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(54) **TRANSMISSION DEVICE WITH IMPAIRMENT COMPENSATION AND METHODS FOR USE THEREWITH**

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(56) **References Cited**

U.S. PATENT DOCUMENTS

529,290 A 11/1894 Harry et al.
1,721,785 A 7/1929 Meyer
1,860,123 A 5/1932 Yagi
2,129,711 A 9/1938 Southworth
2,147,717 A 2/1939 Schelkunoff
2,187,908 A 1/1940 McCreary
2,199,083 A 4/1940 Schelkunoff
2,232,179 A 2/1941 King
2,283,935 A 5/1942 King
2,398,095 A 4/1946 Katzin
2,402,622 A 6/1946 Hansen
2,407,068 A 9/1946 Fiske et al.
2,407,069 A 9/1946 Fiske

(Continued)

FOREIGN PATENT DOCUMENTS

AU 565039 B2 9/1987
AU 7261000 A 4/2001

(Continued)

OTHER PUBLICATIONS

"A New Approach to Outdoor DAS Network Physical Layer Using E-Line Technology", Corridor Systems, Mar. 2011, 5 pages.

(Continued)

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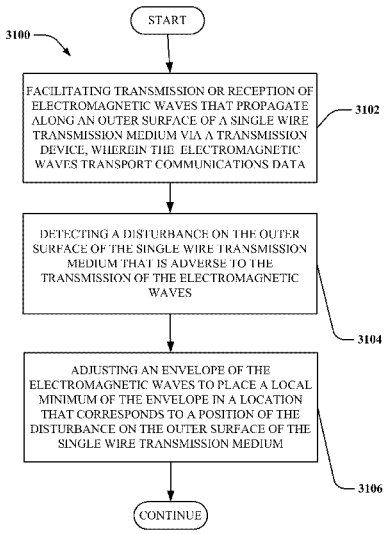
(57) **ABSTRACT**

Aspects of the subject disclosure may include, for example, a waveguide system that includes a transmission device having a coupler positioned with respect to a transmission medium to facilitate transmission or reception of electromagnetic waves that transport communications data. The electromagnetic waves propagate along an outer surface of the transmission medium. A training controller detects an impairment on the transmission medium adverse to the transmission or reception of the electromagnetic waves and adjusts the electromagnetic waves to reduce the effects of the impairment on the transmission medium. Other embodiments are disclosed.

21 Claims, 24 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

2,411,338 A 11/1946 Roberts
2,415,807 A 2/1947 Barrow et al.
2,420,007 A 5/1947 Olden
2,422,058 A 6/1947 Whinnery
2,432,134 A 12/1947 Bagnall
2,461,005 A 2/1949 Southworth
2,471,021 A 5/1949 Bradley
2,514,679 A 7/1950 Southworth
2,519,603 A 8/1950 Reber
2,540,839 A 2/1951 Southworth
2,542,980 A 2/1951 Barrow
2,557,110 A 6/1951 Jaynes
2,562,281 A 7/1951 Mumford
2,596,190 A 5/1952 Wiley
2,677,055 A 4/1954 Allen
2,685,068 A 7/1954 Goubau
2,688,732 A 9/1954 Kock
2,691,766 A 10/1954 Clapp
2,706,279 A 4/1955 Aron
2,711,514 A 6/1955 Rines
2,723,378 A 11/1955 Clavier et al.
2,727,232 A 12/1955 Pryga
2,740,826 A 4/1956 Bondon
2,745,100 A 5/1956 Marie
2,749,545 A 6/1956 Kostriza
2,754,513 A 7/1956 Goubau
2,761,137 A 8/1956 Atta et al.
2,769,147 A 10/1956 Black et al.
2,794,959 A 6/1957 Fox
2,805,415 A 9/1957 Berkowitz
2,806,972 A 9/1957 Sensiper
2,810,111 A 10/1957 Cohn
2,820,083 A 1/1958 Hendrix
2,835,871 A 5/1958 Raabe
2,867,776 A 1/1959 Wilkinson, Jr.
2,914,741 A 11/1959 Unger
2,921,277 A 1/1960 Goubau
2,972,148 A 2/1961 Rupp et al.
2,974,297 A 3/1961 Ros
3,040,278 A 6/1962 Griemsmann et al.
3,072,870 A 1/1963 Walker
3,101,472 A 8/1963 Goubau
3,109,175 A 10/1963 Lloyd
3,129,356 A 4/1964 Phillips
3,134,951 A 5/1964 Huber et al.
3,146,297 A 8/1964 Hahne
3,146,453 A 8/1964 Hagaman
3,201,724 A 8/1965 Hafner
3,218,384 A 11/1965 Shaw
3,234,559 A 2/1966 Bartholoma et al.
3,255,454 A 6/1966 Walter et al.
3,296,364 A 1/1967 Jefferson et al.
3,316,344 A 4/1967 Toms et al.
3,316,345 A 4/1967 Toms et al.
3,321,763 A 5/1967 Ikrath et al.
3,389,394 A 6/1968 Lewis et al.
3,392,395 A 7/1968 Hannan
3,411,112 A 11/1968 Honig et al.
3,413,642 A 11/1968 Cook
3,414,903 A 12/1968 Bartlett et al.
3,427,573 A 2/1969 White et al.
3,459,873 A 8/1969 Harris et al.
3,487,158 A 12/1969 Killian
3,500,422 A 3/1970 Grady et al.
3,509,463 A 4/1970 Woodward et al.
3,522,560 A 8/1970 Hayany
3,524,192 A 8/1970 Sakiotis et al.
3,530,481 A 9/1970 Tanaka et al.
3,531,803 A 9/1970 Hudspeth et al.
3,557,341 A 1/1971 Sochilin et al.
3,589,121 A 6/1971 Mulvey
3,609,247 A 9/1971 Halstead
3,623,114 A 11/1971 Seaton
3,668,459 A 6/1972 Symons et al.
3,668,574 A 6/1972 Barlow
3,672,202 A 6/1972 Barber et al.
3,686,596 A 8/1972 Albee
3,699,574 A 10/1972 Plunk et al.
3,725,937 A 4/1973 Schreiber
3,772,528 A 11/1973 Anderson et al.
3,806,931 A 4/1974 Wright
3,833,909 A 9/1974 Schaufelberger
3,835,407 A 9/1974 Yariv et al.
3,896,380 A 7/1975 Martin
3,935,577 A 1/1976 Hansen et al.
3,936,838 A 2/1976 Foldes et al.
4,010,799 A 3/1977 Kern et al.
4,020,431 A 4/1977 Saunders et al.
4,026,632 A 5/1977 Hill et al.
4,030,048 A 6/1977 Foldes et al.
4,035,054 A 7/1977 Lattanzi et al.
4,080,600 A 3/1978 Toman et al.
4,123,759 A 10/1978 Hines et al.
4,149,170 A 4/1979 Campbell et al.
4,156,241 A 5/1979 Mobley et al.
4,190,137 A 2/1980 Shimada et al.
4,210,357 A 7/1980 Adachi et al.
4,216,449 A 8/1980 Kach
4,234,753 A 11/1980 Clutter
4,238,974 A 12/1980 Fawcett et al.
4,246,584 A 1/1981 Noerpel et al.
4,274,097 A 6/1981 Krall et al.
4,278,955 A 7/1981 Lunden et al.
4,293,833 A 10/1981 Popa et al.
4,316,646 A 2/1982 Siebens et al.
4,319,074 A 3/1982 Yaste et al.
4,329,690 A 5/1982 Parker et al.
4,333,082 A 6/1982 Susman et al.
4,336,719 A 6/1982 Lynnworth
4,345,256 A 8/1982 Rainwater et al.
4,366,565 A 12/1982 Herskowitz
4,378,143 A 3/1983 Winzer et al.
4,398,058 A 8/1983 Gerth et al.
4,398,121 A 8/1983 Chodorow et al.
4,482,899 A 11/1984 Dragone et al.
4,491,386 A 1/1985 Negishi et al.
4,525,432 A 6/1985 Saito et al.
4,533,875 A 8/1985 Lau et al.
4,541,303 A 9/1985 Kuzunishi et al.
4,550,271 A 10/1985 Lau et al.
4,556,271 A 12/1985 Hubbard
4,558,325 A 12/1985 Stroem et al.
4,566,012 A 1/1986 Choung et al.
4,567,401 A 1/1986 Barnett et al.
4,573,215 A 2/1986 Oates et al.
4,598,262 A 7/1986 Chen et al.
4,604,627 A 8/1986 Saad et al.
4,636,753 A 1/1987 Geller et al.
4,641,916 A 2/1987 Oestreich et al.
4,660,050 A 4/1987 Phillips et al.
4,665,660 A 5/1987 Krall et al.
4,680,558 A 7/1987 Ghosh et al.
4,704,611 A 11/1987 Edwards et al.
4,715,695 A 12/1987 Nishimura et al.
4,730,172 A 3/1988 Bengeult
4,730,888 A 3/1988 Darcie et al.
4,731,810 A 3/1988 Watkins
4,743,916 A 5/1988 Bengeult
4,749,244 A 6/1988 Luh
4,758,962 A 7/1988 Fernandes
4,764,738 A 8/1988 Fried et al.
4,772,891 A 9/1988 Svy
4,786,913 A 11/1988 Barendregt et al.
4,792,812 A 12/1988 Rinehart et al.
4,799,031 A 1/1989 Lang et al.
4,818,963 A 4/1989 Green et al.
4,818,990 A 4/1989 Fernandes
4,829,310 A 5/1989 Losee et al.
4,831,346 A 5/1989 Brooker et al.
4,835,517 A 5/1989 van der Gracht et al.
4,845,508 A 7/1989 Krall et al.
4,849,611 A 7/1989 Whitney et al.
4,851,788 A 7/1989 Ives et al.
4,873,534 A 10/1989 Wohlleben et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,886,980 A 12/1989 Fernandes et al.
4,897,663 A 1/1990 Kusano et al.
4,904,996 A 2/1990 Fernandes
4,915,468 A 4/1990 Kim et al.
4,929,962 A 5/1990 Begout et al.
4,931,808 A 6/1990 Munson et al.
4,946,202 A 8/1990 Perricone et al.
4,977,618 A 12/1990 Allen
5,006,846 A 4/1991 Granville et al.
5,015,914 A 5/1991 Ives et al.
5,017,936 A 5/1991 Massey et al.
5,017,937 A 5/1991 Newham et al.
5,019,832 A 5/1991 Ekdahl et al.
5,042,903 A 8/1991 Jakubowski et al.
5,043,538 A 8/1991 Hughey et al.
5,043,629 A 8/1991 Doane et al.
5,044,722 A 9/1991 Voser et al.
5,082,349 A 1/1992 Cordova-Plaza et al.
5,086,467 A 2/1992 Malek
5,109,232 A 4/1992 Monte et al.
5,117,237 A 5/1992 Legg
5,132,968 A 7/1992 Cephus
5,134,251 A 7/1992 Martin et al.
5,134,965 A 8/1992 Tokuda et al.
5,142,767 A 9/1992 Adams et al.
5,148,509 A 9/1992 Kannabiran et al.
5,153,676 A 10/1992 Bergh et al.
5,174,164 A 12/1992 Wilheim et al.
5,182,427 A 1/1993 McGaffigan et al.
5,187,409 A 2/1993 Ito et al.
5,198,823 A 3/1993 Litchford et al.
5,212,755 A 5/1993 Holmberg et al.
5,214,394 A 5/1993 Wong et al.
5,235,662 A 8/1993 Prince et al.
5,248,876 A 9/1993 Kerstens et al.
5,254,809 A 10/1993 Martin
5,265,266 A 11/1993 Trinh
5,266,961 A 11/1993 Milroy et al.
5,278,687 A 1/1994 Jannson et al.
5,291,211 A 3/1994 Tropper et al.
5,311,596 A 5/1994 Scott et al.
5,329,285 A 7/1994 McCandless et al.
5,341,088 A 8/1994 Davis
5,345,522 A 9/1994 Vali et al.
5,371,623 A 12/1994 Eastmond et al.
5,380,224 A 1/1995 DiCicco
5,389,442 A 2/1995 Kathiresan et al.
5,410,318 A 4/1995 Wong et al.
5,412,654 A 5/1995 Perkins
5,434,575 A 7/1995 Jelinek et al.
5,440,660 A 8/1995 Dombrowski et al.
5,479,176 A 12/1995 Zavrel et al.
5,481,268 A 1/1996 Higgins
5,482,525 A 1/1996 Kajioka et al.
5,486,839 A 1/1996 Rodeffer et al.
5,495,546 A 2/1996 Bottoms et al.
5,499,311 A 3/1996 DeCusatis et al.
5,512,906 A 4/1996 Speciale et al.
5,515,059 A 5/1996 How et al.
5,528,208 A 6/1996 Kobayashi et al.
5,543,000 A 8/1996 Lique
5,559,359 A 9/1996 Reyes
5,566,022 A 10/1996 Segev
5,566,196 A 10/1996 Scifres
5,592,183 A 1/1997 Henf
5,619,015 A 4/1997 Kirma
5,637,521 A 6/1997 Rhodes et al.
5,640,168 A 6/1997 Heger et al.
5,650,788 A 7/1997 Jha
5,652,554 A 7/1997 Krieg et al.
5,671,304 A 9/1997 Duguay
5,677,909 A 10/1997 Heide
5,684,495 A 11/1997 Dyott et al.
5,724,168 A 3/1998 Oschmann et al.
5,784,683 A 7/1998 Sistanizadeh et al.
5,793,334 A 8/1998 Harrison et al.
5,818,396 A 10/1998 Harrison et al.
5,818,512 A 10/1998 Fuller
5,850,199 A 12/1998 Wan et al.
5,854,608 A 12/1998 Leisten
5,861,843 A 1/1999 Sorace et al.
5,870,060 A 2/1999 Chen et al.
5,873,324 A 2/1999 Kaddas et al.
5,890,055 A 3/1999 Chu et al.
5,898,133 A 4/1999 Bleich et al.
5,898,830 A 4/1999 Wesinger, Jr. et al.
5,900,847 A 5/1999 Ishikawa et al.
5,903,373 A 5/1999 Welch et al.
5,905,949 A 5/1999 Hawkes et al.
5,917,977 A 6/1999 Barrett et al.
5,926,128 A 7/1999 Brash et al.
5,936,589 A 8/1999 Kawahata
5,948,044 A 9/1999 Varley et al.
5,952,964 A 9/1999 Chan et al.
5,952,972 A 9/1999 Ittipiboon et al.
5,977,650 A 11/1999 Rickard et al.
5,982,276 A 11/1999 Stewart
5,986,331 A 11/1999 Letavic et al.
5,994,984 A 11/1999 Stancil et al.
5,994,998 A 11/1999 Fisher et al.
6,005,758 A 12/1999 Spencer et al.
6,011,520 A 1/2000 Howell et al.
6,014,110 A 1/2000 Bridges et al.
6,023,619 A 2/2000 Kaminsky
6,026,208 A 2/2000 Will et al.
6,026,331 A 2/2000 Feldberg et al.
6,037,894 A 3/2000 Pfizenmaier et al.
6,049,647 A 4/2000 Register et al.
6,063,234 A 5/2000 Chen et al.
6,078,297 A 6/2000 Kormanyos et al.
6,088,001 A 7/2000 Burger et al.
6,100,846 A 8/2000 Li et al.
6,103,031 A 8/2000 Aeschbacher et al.
6,114,998 A 9/2000 Schefte et al.
6,140,911 A 10/2000 Fisher et al.
6,150,612 A 11/2000 Grandy et al.
6,151,145 A 11/2000 Srivastava et al.
6,154,488 A 11/2000 Hunt
6,158,383 A 12/2000 Watanabe et al.
6,166,694 A 12/2000 Ying et al.
6,184,828 B1 2/2001 Shoki et al.
6,195,395 B1 2/2001 Frodsham et al.
6,208,161 B1 3/2001 Suda et al.
6,211,837 B1 4/2001 Crouch et al.
6,222,503 B1 4/2001 Gietema et al.
6,225,960 B1 5/2001 Collins et al.
6,229,327 B1 5/2001 Boll et al.
6,239,379 B1 5/2001 Cotter et al.
6,246,821 B1 6/2001 Hemken et al.
6,259,337 B1 7/2001 Wen et al.
6,266,025 B1 7/2001 Popa et al.
6,271,790 B2 8/2001 Smith et al.
6,271,952 B1 8/2001 Epworth et al.
6,278,357 B1 8/2001 Croushore et al.
6,282,354 B1 8/2001 Jones et al.
6,292,143 B1 9/2001 Romanofsky et al.
6,301,420 B1 10/2001 Greenaway et al.
6,323,819 B1 11/2001 Ergene et al.
6,329,959 B1 12/2001 Varadan et al.
6,351,247 B1 2/2002 Linstrom et al.
6,362,789 B1 3/2002 Trumbull et al.
6,366,238 B1 4/2002 DeMore et al.
6,404,773 B1 6/2002 Williams et al.
6,421,021 B1 7/2002 Rupp et al.
6,433,736 B1 8/2002 Timothy et al.
6,436,536 B2 8/2002 Peruzzotti et al.
6,445,774 B1 9/2002 Kidder et al.
6,452,467 B1 9/2002 McEwan
6,455,769 B1 9/2002 Belli et al.
6,456,251 B1 9/2002 Rao et al.
6,462,700 B1 10/2002 Schmidt et al.
6,469,676 B1 10/2002 Fehrenbach et al.
6,483,470 B1 11/2002 Hohnstein et al.
6,489,928 B2 12/2002 Sakurada

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,501,433 B2 12/2002 Popa et al.
6,515,635 B2 2/2003 Chiang et al.
6,522,305 B2 2/2003 Sharman et al.
6,531,991 B2 3/2003 Adachi et al.
6,542,739 B1 4/2003 Garner
6,549,106 B2 4/2003 Martin et al.
6,549,173 B1 4/2003 King et al.
6,563,981 B2 5/2003 Weisberg et al.
6,567,573 B1 5/2003 Domash et al.
6,573,813 B1 6/2003 Joannopoulos et al.
6,580,295 B2 6/2003 Takekuma et al.
6,584,252 B1 6/2003 Schier et al.
6,596,944 B1 7/2003 Clark et al.
6,606,066 B1 8/2003 Fawcett et al.
6,606,077 B2 8/2003 Ebling et al.
6,631,229 B1 10/2003 Norris et al.
6,639,566 B2 10/2003 Knop et al.
6,650,296 B2 11/2003 Wong et al.
6,653,598 B2 11/2003 Sullivan et al.
6,659,655 B2 12/2003 Dair et al.
6,671,824 B1 12/2003 Hyland et al.
6,677,899 B1 1/2004 Lee et al.
6,683,580 B2 1/2004 Kuramoto
6,686,832 B2 2/2004 Abraham et al.
6,686,873 B2 2/2004 Patel et al.
6,686,875 B1 2/2004 Wolfson et al.
6,697,030 B2 2/2004 Gleener
6,703,981 B2 3/2004 Meitzler et al.
6,714,165 B2 3/2004 Verstraeten
6,727,470 B2 4/2004 Reichle et al.
6,731,649 B1 5/2004 Silverman
6,741,705 B1 5/2004 Nelson et al.
6,750,827 B2 6/2004 Manasson et al.
6,765,479 B2 7/2004 Stewart et al.
6,768,456 B1 7/2004 Lalezari et al.
6,768,471 B2 7/2004 Bostwick et al.
6,768,474 B2 7/2004 Hunt et al.
6,771,216 B2 8/2004 Patel et al.
6,771,225 B2 8/2004 Tits et al.
6,771,739 B1 8/2004 Beamon et al.
6,788,865 B2 9/2004 Kawanishi et al.
6,788,951 B2 9/2004 Aoki et al.
6,789,119 B1 9/2004 Zhu et al.
6,812,895 B2 11/2004 Anderson et al.
6,822,615 B2 11/2004 Quan et al.
6,839,846 B2 1/2005 Mangold et al.
6,842,157 B2 1/2005 Phelan et al.
6,842,430 B1 1/2005 Melnik et al.
6,850,128 B2 2/2005 Park
6,859,185 B2 2/2005 Royalty et al.
6,859,590 B1 2/2005 Zaccone
6,867,744 B2 3/2005 Toncich et al.
6,868,258 B2 3/2005 Hayata et al.
6,870,465 B1 3/2005 Song et al.
6,885,674 B2 4/2005 Hunt et al.
6,886,065 B2 4/2005 Sides et al.
6,888,623 B2 5/2005 Clements
6,901,064 B2 5/2005 Billhartz et al.
6,904,218 B2 6/2005 Sun et al.
6,906,676 B2 6/2005 Killen et al.
6,909,893 B2 6/2005 Aoki et al.
6,917,974 B1 7/2005 Stytz et al.
6,920,289 B2 7/2005 Zimmerman et al.
6,922,135 B2 7/2005 Abraham et al.
6,934,655 B2 8/2005 Jones et al.
6,944,555 B2 9/2005 Blackett et al.
6,947,635 B2 9/2005 Kohns et al.
6,950,567 B2 9/2005 Kline et al.
6,958,729 B1 10/2005 Metz et al.
6,965,302 B2 11/2005 Mollenkopf et al.
6,965,355 B1 11/2005 Durham et al.
6,972,729 B2 12/2005 Wang et al.
6,980,091 B2 12/2005 White, II et al.
6,982,611 B2 1/2006 Cope et al.
6,982,679 B2 1/2006 Kralovec et al.
6,992,639 B1 1/2006 Lier et al.
6,999,667 B2 2/2006 Jang et al.
7,008,120 B2 3/2006 Zaborsky et al.
7,009,471 B2 3/2006 Elmore
7,012,572 B1 3/2006 Schaffner et al.
7,016,585 B2 3/2006 Diggle, III et al.
7,023,400 B2 4/2006 Hill et al.
7,032,016 B2 4/2006 Cerami et al.
7,039,048 B1 5/2006 Monta et al.
7,042,403 B2 5/2006 Colburn et al.
7,042,416 B2 5/2006 Kingsley et al.
7,042,420 B2 5/2006 Ebling et al.
7,054,286 B2 5/2006 Ertel et al.
7,054,513 B2 5/2006 Herz et al.
7,055,148 B2 5/2006 Marsh et al.
7,068,998 B2 6/2006 Zavidniak et al.
7,098,405 B2 8/2006 Glew et al.
7,098,773 B2 8/2006 Berkman et al.
7,102,581 B1 9/2006 West et al.
7,106,265 B2 9/2006 Robertson et al.
7,113,002 B2 9/2006 Otsuka et al.
7,113,134 B1 9/2006 Berkman et al.
7,119,755 B2 10/2006 Harvey et al.
7,120,345 B2 10/2006 Naitou et al.
7,123,801 B2 10/2006 Fitz et al.
7,126,711 B2 10/2006 Fruth
7,130,516 B2 10/2006 Wu et al.
7,132,950 B2 11/2006 Stewart et al.
7,133,930 B2 11/2006 Sabio et al.
7,134,012 B2 11/2006 Doyle et al.
7,134,135 B2 11/2006 Cerami et al.
7,137,605 B1 11/2006 Guertler et al.
7,145,440 B2 12/2006 Gerszberg et al.
7,151,497 B2 12/2006 Crystal et al.
7,161,934 B2 1/2007 Buchsbaum et al.
7,167,139 B2 1/2007 Kim et al.
7,171,087 B2 1/2007 Takahashi et al.
7,176,589 B2 2/2007 Rouquette et al.
7,180,459 B2 2/2007 Damini et al.
7,180,467 B2 2/2007 Fabrega-Sanchez
7,194,528 B1 3/2007 Davidow et al.
7,200,658 B2 4/2007 Goeller et al.
7,205,950 B2 4/2007 Imai et al.
7,212,163 B2 5/2007 Huang et al.
7,215,220 B1 5/2007 Jia et al.
7,215,928 B2 5/2007 Gage et al.
7,218,285 B2 5/2007 Davis et al.
7,224,243 B2 5/2007 Cope et al.
7,224,320 B2 5/2007 Cook et al.
7,228,123 B2 6/2007 Moursund et al.
7,234,413 B2 6/2007 Suzuki et al.
7,234,895 B2 6/2007 Richardson et al.
7,239,284 B1 7/2007 Staal et al.
7,243,610 B2 7/2007 Ishii et al.
7,248,148 B2 7/2007 Kline et al.
7,260,424 B2 8/2007 Schmidt et al.
7,266,154 B2 9/2007 Gundrum et al.
7,266,275 B2 9/2007 Hansen et al.
7,272,281 B2 9/2007 Stahulak et al.
7,274,305 B1 9/2007 Luttrell
7,276,990 B2 10/2007 Sievenpiper et al.
7,280,033 B2 10/2007 Berkman et al.
7,289,704 B1 10/2007 Wagman et al.
7,297,869 B2 11/2007 Hiller et al.
7,307,596 B1 12/2007 West et al.
7,308,370 B2 12/2007 Mason, Jr. et al.
7,310,335 B1 12/2007 Garcia-Luna-Aceves et al.
7,311,605 B2 12/2007 Moser
7,313,312 B2 12/2007 Kimball et al.
7,315,678 B2 1/2008 Siegel
7,319,717 B2 1/2008 Zitting et al.
7,321,291 B2 1/2008 Gidge et al.
7,324,046 B1 1/2008 Wu et al.
7,329,815 B2 2/2008 Johnston et al.
7,333,064 B1 2/2008 Timothy et al.
7,333,593 B2 2/2008 Beamon et al.
7,339,466 B2 3/2008 Mansfield et al.
7,339,897 B2 3/2008 Larsson et al.
7,340,768 B2 3/2008 Rosenberger et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,345,623 B2 3/2008 McEwan et al.
7,346,244 B2 3/2008 Gowan et al.
7,346,359 B2 3/2008 Damarla et al.
7,355,560 B2 4/2008 Nagai et al.
7,358,808 B2 4/2008 Berkman et al.
7,369,085 B1 5/2008 Jacomb-Hood et al.
7,380,272 B2 5/2008 Sharp et al.
7,381,089 B2 6/2008 Hosler, Sr.
7,383,577 B2 6/2008 Hrastar et al.
7,397,422 B2 7/2008 Tekawy et al.
7,398,946 B1 7/2008 Marshall
7,408,426 B2 8/2008 Broyde et al.
7,417,587 B2 8/2008 Iskander et al.
7,418,178 B2 8/2008 Kudou et al.
7,420,474 B1 9/2008 Elks et al.
7,430,932 B2 10/2008 Mekhanoshin et al.
7,443,334 B2 10/2008 Rees et al.
7,444,404 B2 10/2008 Wetherall et al.
7,450,001 B2 11/2008 Berkman
7,453,352 B2 11/2008 Kline et al.
7,453,393 B2 11/2008 Duivenvoorden et al.
7,456,650 B2 11/2008 Lee et al.
7,459,834 B2 12/2008 Knowles et al.
7,463,877 B2 12/2008 Iwamura
7,465,879 B2 12/2008 Glew et al.
7,466,225 B2 12/2008 White, II et al.
7,468,657 B2 12/2008 Yaney
7,492,317 B2 2/2009 Tinsley et al.
7,496,674 B2 2/2009 Jorgensen et al.
7,509,009 B2 3/2009 Suzuki et al.
7,509,675 B2 3/2009 Aaron et al.
7,512,090 B2 3/2009 Benitez Pelaez et al.
7,516,487 B1 4/2009 Szeto et al.
7,518,952 B1 4/2009 Padden et al.
7,522,115 B2 4/2009 Waltman et al.
7,522,812 B2 4/2009 Zitting
7,525,501 B2 4/2009 Black et al.
7,531,803 B2 5/2009 Mittleman et al.
7,532,792 B2 5/2009 Skovgaard et al.
7,539,381 B2 5/2009 Chen et al.
7,545,818 B2 6/2009 Chen et al.
7,546,214 B2 6/2009 Rivers, Jr. et al.
7,554,998 B2 6/2009 Simonsson et al.
7,555,182 B2 6/2009 Martin et al.
7,555,186 B2 6/2009 Flammer et al.
7,555,187 B2 6/2009 Bickham et al.
7,561,025 B2 7/2009 Gerszberg et al.
7,567,154 B2 7/2009 Elmore
7,567,740 B2 7/2009 Bayindir et al.
7,570,137 B2 8/2009 Kintis et al.
7,570,470 B2 8/2009 Holley
7,580,643 B2 8/2009 Moore et al.
7,583,074 B1 9/2009 Lynch et al.
7,584,470 B2 9/2009 Barker et al.
7,589,686 B2 9/2009 Balzovsky et al.
7,590,404 B1 9/2009 Johnson et al.
7,591,020 B2 9/2009 Kammer et al.
7,596,222 B2 9/2009 Jonas et al.
7,598,844 B2 10/2009 Corcoran et al.
7,602,333 B2 10/2009 Hiramatsu et al.
7,602,815 B2 10/2009 Houghton et al.
7,620,370 B2 11/2009 Barak et al.
7,625,131 B2 12/2009 Zienkewicz et al.
7,626,489 B2 12/2009 Berkman et al.
7,634,250 B1 12/2009 Prasad et al.
7,640,562 B2 12/2009 Bouilloux-Lafont et al.
7,640,581 B1 12/2009 Brenton et al.
7,653,363 B2 1/2010 Karr et al.
RE41,147 E 2/2010 Pang et al.
7,656,167 B1 2/2010 McLean
7,660,252 B1 2/2010 Huang et al.
7,660,328 B1 2/2010 Oz et al.
7,664,117 B2 2/2010 Lou et al.
7,669,049 B2 2/2010 Wang et al.
7,671,701 B2 3/2010 Radtke
7,671,820 B2 3/2010 Tokoro et al.
7,676,679 B2 3/2010 Weis et al.
7,680,478 B2 3/2010 Willars et al.
7,680,516 B2 3/2010 Lovberg et al.
7,680,561 B2 3/2010 Rodgers et al.
7,683,848 B2 3/2010 Gerding et al.
7,684,383 B1 3/2010 Thompson et al.
7,693,079 B2 4/2010 Cerami et al.
7,693,162 B2 4/2010 McKenna et al.
7,693,939 B2 4/2010 Wu et al.
7,701,931 B2 4/2010 Kajiwara
7,705,747 B2 4/2010 Twitchell, Jr.
7,715,672 B2 5/2010 Dong et al.
7,716,660 B2 5/2010 Mackay et al.
7,724,782 B2 5/2010 Wang et al.
7,728,772 B2 6/2010 Mortazawi et al.
7,734,717 B2 6/2010 Saarimäki et al.
7,743,403 B2 6/2010 McCarty et al.
7,747,356 B2 6/2010 Andarawis et al.
7,747,774 B2 6/2010 Aaron
7,750,244 B1 7/2010 Melding et al.
7,750,763 B2 7/2010 Praβmayer et al.
7,760,978 B2 7/2010 DiGiovanni et al.
7,761,079 B2 7/2010 Mollenkopf et al.
7,764,943 B2 7/2010 Radtke et al.
7,773,664 B2 8/2010 Myers et al.
7,782,156 B2 8/2010 Woods et al.
7,783,195 B2 8/2010 Riggsby
7,786,894 B2 8/2010 Polk et al.
7,786,945 B2 8/2010 Baldauf et al.
7,786,946 B2 8/2010 Diaz et al.
7,791,549 B2 9/2010 Clymer et al.
7,795,877 B2 9/2010 Radtke et al.
7,795,994 B2 9/2010 Radtke et al.
7,796,025 B2 9/2010 Berkman et al.
7,796,890 B1 9/2010 Johnson
7,805,029 B2 9/2010 Bayindir et al.
7,808,441 B2 10/2010 Parsche et al.
7,809,223 B2 10/2010 Miyabe et al.
7,812,778 B2 10/2010 Hasegawa
7,813,344 B2 10/2010 Cheswick
7,825,793 B1 11/2010 Spillman et al.
7,826,602 B1 11/2010 Hunyady et al.
7,827,610 B2 11/2010 Wang et al.
7,830,228 B2 11/2010 Brown et al.
7,835,600 B1 11/2010 Yap et al.
7,848,517 B2 12/2010 Britz et al.
7,852,837 B1 * 12/2010 Au H04B 1/74 370/389
7,869,391 B2 1/2011 Lee et al.
7,872,610 B2 1/2011 Motzer et al.
7,873,249 B2 1/2011 Kachmar et al.
7,876,174 B2 1/2011 Radtke et al.
7,884,285 B2 2/2011 Spencer
7,884,648 B2 2/2011 Broyde et al.
7,885,542 B2 2/2011 Riggsby et al.
7,889,148 B2 2/2011 Diaz et al.
7,889,149 B2 2/2011 Diaz et al.
7,890,053 B2 2/2011 Washiro
7,894,770 B2 2/2011 Washiro et al.
7,903,918 B1 3/2011 Bickham et al.
7,903,972 B2 3/2011 Riggsby et al.
7,929,940 B1 4/2011 Dianda et al.
7,930,750 B1 4/2011 Gauvin et al.
7,937,699 B2 5/2011 Schneider et al.
7,958,120 B2 6/2011 Muntz et al.
7,962,957 B2 6/2011 Keohane et al.
7,965,842 B2 6/2011 Whelan et al.
7,970,937 B2 6/2011 Shuster et al.
7,971,053 B2 6/2011 Norton et al.
7,974,387 B2 7/2011 Lutz et al.
7,983,740 B2 7/2011 Culver et al.
7,986,711 B2 7/2011 Horvath et al.
7,990,329 B2 8/2011 Deng et al.
7,991,877 B2 8/2011 Keohane et al.
7,992,014 B2 8/2011 Langgood et al.
8,013,694 B2 9/2011 Hiramatsu et al.
8,022,885 B2 9/2011 Smoyer et al.
8,022,887 B1 9/2011 Zarnaghi et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,027,391 B2 9/2011 Matsubara et al.
8,036,207 B2 10/2011 Sivakumar et al.
8,049,576 B2 11/2011 Broyde et al.
8,065,099 B2 11/2011 Gibala et al.
8,069,483 B1 11/2011 Matlock et al.
8,072,323 B2 12/2011 Kodama et al.
8,073,810 B2 12/2011 Maes
8,077,049 B2 12/2011 Yaney et al.
8,081,854 B2 12/2011 Yoon et al.
8,089,404 B2 1/2012 Nichols et al.
8,089,952 B2 1/2012 Spade et al.
8,090,379 B2 1/2012 Lambert et al.
8,094,081 B1 1/2012 Bruzzi et al.
8,094,985 B2 1/2012 Imamura et al.
8,098,198 B2 1/2012 Thiesen et al.
RE43,163 E 2/2012 Andrews et al.
8,111,148 B2 2/2012 Parker et al.
8,120,488 B2 2/2012 Bloy et al.
8,121,624 B2 2/2012 Cai et al.
8,129,817 B2 3/2012 Jou et al.
8,131,125 B2 3/2012 De Montmorillon et al.
8,131,266 B2 3/2012 Cai et al.
8,132,239 B2 3/2012 Wahl
8,134,424 B2 3/2012 Kato et al.
8,134,458 B2 3/2012 Lund
8,140,113 B2 3/2012 Rofougaran et al.
8,151,306 B2 4/2012 Rakib
8,156,520 B2 4/2012 Casagrande et al.
8,159,385 B2 4/2012 Farneth et al.
8,159,394 B2 4/2012 Hayes et al.
8,159,742 B2 4/2012 Dong et al.
8,159,933 B2 4/2012 Henry
8,160,064 B2 4/2012 Kokernak et al.
8,160,530 B2 4/2012 Corman et al.
8,160,825 B1 4/2012 Roe, Jr. et al.
8,171,146 B2 5/2012 Chen et al.
8,180,917 B1 5/2012 Yan et al.
8,184,015 B2 5/2012 Lilien et al.
8,184,059 B2 5/2012 Bunch et al.
8,184,311 B2 5/2012 Sakai et al.
8,188,855 B2 5/2012 Sharma et al.
8,199,762 B2 6/2012 Michelson et al.
8,203,501 B2 6/2012 Kim et al.
8,212,635 B2 7/2012 Miller, II et al.
8,213,758 B2 7/2012 Dong et al.
8,218,929 B2 7/2012 Bickham et al.
8,222,919 B2 7/2012 Broyde et al.
8,222,977 B2 7/2012 Oyama et al.
8,225,379 B2 7/2012 Van De Groenendaal
8,237,617 B1 8/2012 Johnson et al.
8,238,824 B2 8/2012 Washiro
8,242,358 B2 8/2012 Park et al.
8,243,603 B2 8/2012 Gossain et al.
8,249,028 B2 8/2012 Porras et al.
8,253,516 B2 8/2012 Miller, II et al.
8,255,952 B2 8/2012 Boylan, III et al.
8,258,743 B2 9/2012 Tyler et al.
8,264,417 B2 9/2012 Snow et al.
8,269,583 B2 9/2012 Miller, II et al.
8,295,301 B2 10/2012 Yonge, III et al.
8,300,538 B2 10/2012 Kim et al.
8,300,640 B2 10/2012 Al-Banna et al.
8,316,228 B2 11/2012 Winslow
8,316,364 B2 11/2012 Stein
8,343,145 B2 1/2013 Brannan
8,344,829 B2 1/2013 Miller, II et al.
8,363,313 B2 1/2013 Nakaguma et al.
8,369,667 B2 2/2013 Rose
8,374,821 B2 2/2013 Rousselle et al.
8,384,600 B2 2/2013 Huang et al.
8,385,978 B2 2/2013 Leung et al.
8,386,198 B2 2/2013 Lancaster
8,390,402 B2 3/2013 Kunes et al.
8,406,239 B2 3/2013 Hurwitz et al.
8,406,593 B2 3/2013 Molin et al.
8,407,687 B2 3/2013 Moshir et al.
8,412,130 B2 4/2013 Suematsu et al.
8,414,326 B2 4/2013 Bowman
8,415,884 B2 4/2013 Chen et al.
8,433,168 B2 4/2013 Filippov et al.
8,434,103 B2 4/2013 Tsuchida et al.
8,458,453 B1 6/2013 Mahalingaiah et al.
8,462,063 B2 6/2013 Gummalla et al.
8,467,363 B2 6/2013 Lea et al.
8,468,244 B2 6/2013 Redlich et al.
8,484,511 B2 7/2013 Tidwell et al.
8,495,718 B2 7/2013 Han et al.
8,497,749 B2 7/2013 Elmore
8,503,845 B2 8/2013 Winzer et al.
8,505,057 B2 8/2013 Rogers
8,509,114 B1 8/2013 Szajdecki
8,514,980 B2 8/2013 Kuhtz
8,515,383 B2 8/2013 Prince et al.
8,516,470 B1 8/2013 Van Rietschote et al.
8,516,474 B2 8/2013 Lamba et al.
8,520,636 B2 8/2013 Xu
8,528,059 B1 9/2013 Labana et al.
8,532,023 B2 9/2013 Buddhikot et al.
8,532,046 B2 9/2013 Hu et al.
8,537,068 B2 9/2013 Martin et al.
8,537,705 B2 9/2013 Afkhamie et al.
8,539,540 B2 9/2013 Zenoni
8,539,569 B2 9/2013 Mansour
8,542,968 B2 9/2013 Dong et al.
8,548,294 B2 10/2013 Toge et al.
8,553,646 B2 10/2013 Kumar
8,561,104 B1 10/2013 Dow et al.
8,561,181 B1 10/2013 Hernacki et al.
8,565,568 B2 10/2013 Bigot-Astruc et al.
8,572,247 B2 10/2013 Larson et al.
8,572,639 B2 10/2013 Ficco
8,572,661 B2 10/2013 Strong et al.
8,578,076 B2 11/2013 Van Der Linden et al.
8,578,486 B2 11/2013 Lifliand et al.
8,584,195 B2 11/2013 Sherlock et al.
8,587,490 B2 11/2013 Niver et al.
8,587,492 B2 11/2013 Runyon et al.
8,588,567 B2 11/2013 Kamps et al.
8,588,991 B1 11/2013 Forbes, Jr.
8,593,238 B2 11/2013 Miller, II et al.
8,604,982 B2 12/2013 Achour et al.
8,604,999 B2 12/2013 Abumrad et al.
8,605,579 B2 12/2013 Abraham et al.
8,612,550 B2 12/2013 Yoo et al.
8,613,020 B2 12/2013 Knudson et al.
8,625,547 B1 1/2014 Miller et al.
8,629,811 B2 1/2014 Grandfield et al.
8,639,934 B2 1/2014 Kruglick
8,653,906 B2 2/2014 Mahon et al.
8,656,458 B2 2/2014 Heffez et al.
8,660,526 B1 2/2014 Heiderscheit et al.
8,660,698 B2 2/2014 Phillips et al.
8,665,102 B2 3/2014 Salewske et al.
8,666,553 B2 3/2014 Phillips et al.
8,674,630 B1 3/2014 Cornelius et al.
8,681,463 B2 3/2014 Franks et al.
8,687,650 B2 4/2014 King
8,688,153 B2 4/2014 Komori et al.
8,699,454 B2 4/2014 Hapsari et al.
8,699,461 B2 4/2014 Qian et al.
8,705,925 B2 4/2014 Terada et al.
8,707,432 B1 4/2014 Rathi et al.
8,711,732 B2 4/2014 Johnson et al.
8,711,806 B2 4/2014 Lim et al.
8,711,857 B2 4/2014 Jackson et al.
8,712,200 B1 4/2014 Abernathy et al.
8,719,938 B2 5/2014 Chasko et al.
8,731,358 B2 5/2014 Pare et al.
8,732,476 B1 5/2014 Van et al.
8,737,793 B2 5/2014 Imamura et al.
8,738,318 B2 5/2014 Spillane
8,743,004 B2 6/2014 Haziza
8,749,449 B2 6/2014 Caldwell et al.
8,750,664 B2 6/2014 Zhang et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,755,659 B2 6/2014 Imamura et al.
8,760,354 B2 6/2014 Clymer et al.
8,761,792 B2 6/2014 Sennett et al.
8,763,097 B2 6/2014 Bhatnagar et al.
8,769,622 B2 7/2014 Chang et al.
8,780,012 B2 7/2014 Llombart Juan et al.
8,782,195 B2 7/2014 Foti
8,786,284 B2 7/2014 Sirigiri et al.
8,786,514 B2 7/2014 Dickie et al.
8,789,091 B2 7/2014 Eldering et al.
8,792,760 B2 7/2014 Choi et al.
8,793,363 B2 7/2014 Sater et al.
8,793,742 B2 7/2014 Macrae et al.
8,804,667 B2 8/2014 Wang
8,806,202 B2 8/2014 Shoemake et al.
8,810,404 B2 8/2014 Bertoncini et al.
8,810,421 B2 8/2014 Deaver, Sr. et al.
8,811,278 B2 8/2014 Takei et al.
8,817,741 B2 8/2014 Shaheen
8,830,112 B1 9/2014 Buehler et al.
8,836,607 B2 9/2014 Cook et al.
8,839,350 B1 9/2014 Mcnair et al.
8,847,840 B1 9/2014 Diaz et al.
8,856,239 B1 10/2014 Oliver et al.
8,856,530 B2 10/2014 Patti et al.
8,863,245 B1 10/2014 Abhyanker
8,867,226 B2 10/2014 Tyhach et al.
8,872,032 B2 10/2014 Lin et al.
8,875,224 B2 10/2014 Gross et al.
8,878,740 B2 11/2014 Coupland et al.
8,881,588 B2 11/2014 Baer et al.
8,885,689 B2 11/2014 Blasco Claret et al.
8,887,212 B2 11/2014 Dua
8,890,759 B2 11/2014 Pantea et al.
8,893,246 B2 11/2014 Jover Segura et al.
8,897,697 B1 11/2014 Bennett et al.
8,901,916 B2 12/2014 Jones et al.
8,903,214 B2 12/2014 Alkeskjold
8,907,222 B2 12/2014 Stransky
8,913,862 B1 12/2014 Emmerich et al.
8,917,215 B2 12/2014 Pohl
8,917,964 B2 12/2014 Chamberlain et al.
8,918,108 B2 12/2014 Arad et al.
8,925,079 B2 12/2014 Vaidyanathan et al.
8,934,747 B2 1/2015 Conrad et al.
8,937,577 B2 1/2015 Neto et al.
8,938,144 B2 1/2015 Hennink et al.
8,941,912 B2 1/2015 Tanigawa et al.
8,955,051 B2 2/2015 Marzii
8,955,075 B2 2/2015 Von Bokern et al.
8,957,818 B2 2/2015 Chen
8,958,665 B2 2/2015 Evans et al.
8,963,790 B2 2/2015 Brown
8,964,433 B2 * 2/2015 Hai-Maharsi H01H 33/008 363/126
8,966,609 B2 2/2015 Lee et al.
8,970,438 B2 3/2015 Hager et al.
8,984,113 B2 3/2015 Li et al.
8,994,474 B2 3/2015 Mahon et al.
8,996,188 B2 3/2015 Frader-Thompson et al.
8,996,728 B2 3/2015 Cochinwala et al.
9,000,353 B2 4/2015 Seo et al.
9,001,689 B1 4/2015 Hinman et al.
9,003,492 B2 4/2015 Katar
9,008,513 B2 4/2015 Kim et al.
9,009,460 B2 4/2015 Chen
9,015,467 B2 4/2015 Buer
9,021,251 B2 4/2015 Chawla
9,021,575 B2 4/2015 Martini
9,037,516 B2 5/2015 Abhyanker
9,042,812 B1 5/2015 Bennett et al.
9,082,307 B2 7/2015 Sharawi
9,094,407 B1 7/2015 Matthieu
9,098,325 B2 8/2015 Reddin
9,106,617 B2 8/2015 Kshirsagar et al.
9,119,127 B1 * 8/2015 Henry H04W 36/22
9,128,941 B2 9/2015 Shulman
9,134,945 B2 9/2015 Husain
2001/0030789 A1 10/2001 Jiang et al.
2002/0002040 A1 1/2002 Kline et al.
2002/0024424 A1 2/2002 Burns et al.
2002/0040439 A1 4/2002 Kellum
2002/0069417 A1 6/2002 Kliger et al.
2002/0099949 A1 7/2002 Fries et al.
2002/0111997 A1 8/2002 Herlihy
2002/0156917 A1 10/2002 Nye
2002/0186694 A1 12/2002 Mahajan et al.
2003/0002476 A1 1/2003 Chung et al.
2003/0010528 A1 1/2003 Niles
2003/0049003 A1 3/2003 Ahmad et al.
2003/0095208 A1 5/2003 Chouraqui et al.
2003/0152331 A1 8/2003 Dair et al.
2003/0188308 A1 10/2003 Kizuka
2003/0190110 A1 10/2003 Kline et al.
2003/0202756 A1 10/2003 Hurley et al.
2003/0210197 A1 11/2003 Cencich et al.
2004/0015725 A1 1/2004 Boneh et al.
2004/0023640 A1 2/2004 Ballai
2004/0048596 A1 3/2004 Wyrzykowska et al.
2004/0054425 A1 3/2004 Elmore
2004/0100343 A1 5/2004 Tsu et al.
2004/0104410 A1 6/2004 Gilbert et al.
2004/0163135 A1 8/2004 Giaccherini et al.
2004/0165669 A1 8/2004 Otsuka et al.
2004/0196784 A1 10/2004 Larsson et al.
2004/0212481 A1 10/2004 Abraham
2004/0213147 A1 10/2004 Wiese et al.
2004/0213189 A1 10/2004 Alspaugh et al.
2004/0213294 A1 10/2004 Hughes
2004/0250069 A1 12/2004 Kosamo et al.
2005/0005854 A1 1/2005 Suzuki et al.
2005/0017825 A1 1/2005 Hansen
2005/0068223 A1 3/2005 Vavik
2005/0069321 A1 3/2005 Sullivan
2005/0097396 A1 5/2005 Wood
2005/0102185 A1 5/2005 Barker et al.
2005/0111533 A1 * 5/2005 Berkman H04B 3/542 375/220
2005/0169401 A1 8/2005 Abraham et al.
2005/0177463 A1 8/2005 Crutchfield et al.
2005/0212626 A1 9/2005 Takamatsu
2005/0219135 A1 10/2005 Lee et al.
2005/0226353 A1 10/2005 Gebara et al.
2005/0258920 A1 11/2005 Elmore
2006/0034724 A1 2/2006 Hamano et al.
2006/0053486 A1 3/2006 Wesinger et al.
2006/0082516 A1 4/2006 Strickland
2006/0111047 A1 5/2006 Louberg et al.
2006/0114925 A1 6/2006 Gerszberg et al.
2006/0120399 A1 6/2006 Claret et al.
2006/0153878 A1 7/2006 Savarino et al.
2006/0181394 A1 8/2006 Clarke
2006/0187023 A1 8/2006 Iwamura
2006/0192672 A1 8/2006 Gidge et al.
2006/0220833 A1 10/2006 Berkman et al.
2006/0239501 A1 10/2006 Petrovic et al.
2006/0286927 A1 12/2006 Berkman
2007/0022475 A1 1/2007 Rossi et al.
2007/0025386 A1 2/2007 Riedel et al.
2007/0041554 A1 2/2007 Newman
2007/0054622 A1 3/2007 Berkman
2007/0090185 A1 4/2007 Lewkowitz et al.
2007/0105508 A1 5/2007 Tong et al.
2007/0135044 A1 6/2007 Rhodes et al.
2007/0144779 A1 6/2007 Vicente et al.
2007/0252998 A1 11/2007 Berthold et al.
2007/0300280 A1 12/2007 Turner et al.
2008/0003872 A1 1/2008 Chen et al.
2008/0060832 A1 3/2008 Razavi
2008/0120667 A1 5/2008 Zaltsman
2008/0130639 A1 6/2008 Costa-Requena et al.
2008/0143491 A1 6/2008 Deaver et al.
2008/0153416 A1 6/2008 Washiro
2008/0211727 A1 9/2008 Elmore

(56) **References Cited**

U.S. PATENT DOCUMENTS

2008/0247716 A1 10/2008 Thomas et al.
2008/0253723 A1 10/2008 Stokes et al.
2008/0255782 A1 10/2008 Bilac et al.
2008/0267076 A1 10/2008 Laperi et al.
2008/0313691 A1 12/2008 Cholas
2009/0002137 A1 1/2009 Radtke et al.
2009/0007189 A1 1/2009 Gutknecht
2009/0015239 A1 1/2009 Georgiou et al.
2009/0067441 A1 3/2009 Ansari et al.
2009/0079660 A1 3/2009 Elmore
2009/0085726 A1 4/2009 Radtke et al.
2009/0109981 A1 4/2009 Keselman
2009/0129301 A1 5/2009 Belimpasakis
2009/0138931 A1 5/2009 Lin et al.
2009/0144417 A1 6/2009 Kisel et al.
2009/0171780 A1 7/2009 Aldrey et al.
2009/0201133 A1 8/2009 Bruns
2009/0210901 A1 8/2009 Hawkins et al.
2009/0250449 A1 10/2009 Petrenko et al.
2009/0254971 A1 10/2009 Herz et al.
2009/0311960 A1 12/2009 Farahani et al.
2009/0315668 A1 12/2009 Leete, III et al.
2010/0026607 A1 2/2010 Imai
2010/0045447 A1 2/2010 Mollenkopf et al.
2010/0057894 A1 3/2010 Glasser
2010/0085036 A1 4/2010 Banting et al.
2010/0100918 A1 4/2010 Egan, Jr. et al.
2010/0119234 A1 5/2010 Suematsu et al.
2010/0121945 A1 5/2010 Gerber et al.
2010/0153990 A1 6/2010 Ress et al.
2010/0169937 A1 7/2010 Atwal et al.
2010/0175080 A1 7/2010 Yuen et al.
2010/0177894 A1 7/2010 Yasuma et al.
2010/0185614 A1 7/2010 O'Brien et al.
2010/0214185 A1 8/2010 Sammoura et al.
2010/0243633 A1 9/2010 Huynh et al.
2010/0265877 A1 10/2010 Lau et al.
2010/0283693 A1 11/2010 Xie et al.
2010/0284446 A1 11/2010 Mu et al.
2010/0319068 A1 12/2010 Abbadessa et al.
2011/0018704 A1 1/2011 Burrows
2011/0040861 A1 2/2011 Van Der Merwe et al.
2011/0042120 A1 2/2011 Otsuka et al.
2011/0053498 A1 3/2011 Nogueira-Nine
2011/0068893 A1 3/2011 Lahiri
2011/0068988 A1 3/2011 Monte
2011/0107364 A1 5/2011 Lajoie et al.
2011/0109936 A1 5/2011 Coffee et al.
2011/0110404 A1 5/2011 Washiro
2011/0118888 A1* 5/2011 White, II G02B 6/483 700/293
2011/0132658 A1 6/2011 Miller, II et al.
2011/0133865 A1 6/2011 Miller, II et al.
2011/0136432 A1 6/2011 Miller, II et al.
2011/0140911 A1 6/2011 Pant et al.
2011/0141555 A1 6/2011 Fermann et al.
2011/0148578 A1 6/2011 Aloi et al.
2011/0164514 A1 7/2011 Afkhamie et al.
2011/0165847 A1 7/2011 Kawasaki
2011/0219402 A1 9/2011 Candelore et al.
2011/0225046 A1 9/2011 Eldering et al.
2011/0228814 A1 9/2011 Washiro
2011/0268085 A1 11/2011 Barany et al.
2011/0274396 A1 11/2011 Nakajima et al.
2011/0294509 A1 12/2011 Kim et al.
2012/0039366 A1 2/2012 Wood et al.
2012/0046891 A1 2/2012 Yaney et al.
2012/0068903 A1 3/2012 Thevenard et al.
2012/0077485 A1 3/2012 Shin et al.
2012/0084807 A1 4/2012 Thompson et al.
2012/0091820 A1 4/2012 Campanella et al.
2012/0092161 A1 4/2012 West
2012/0102568 A1 4/2012 Tarbotton et al.
2012/0105246 A1 5/2012 Sexton et al.
2012/0117584 A1 5/2012 Gordon
2012/0133373 A1 5/2012 Ali et al.
2012/0144420 A1 6/2012 Del Sordo et al.
2012/0154239 A1 6/2012 Bar-Sade et al.
2012/0181258 A1 7/2012 Shan et al.
2012/0197558 A1 8/2012 Henig et al.
2012/0263152 A1 10/2012 Fischer et al.
2012/0272741 A1 11/2012 Xiao et al.
2012/0287922 A1 11/2012 Heck et al.
2012/0304294 A1 11/2012 Fujiwara
2012/0306708 A1 12/2012 Henderson et al.
2012/0324018 A1 12/2012 Metcalf et al.
2012/0327908 A1 12/2012 Gupta et al.
2012/0329523 A1 12/2012 Stewart et al.
2012/0330756 A1 12/2012 Morris et al.
2013/0002409 A1 1/2013 Molina et al.
2013/0003876 A1 1/2013 Bennett
2013/0039624 A1 2/2013 Scherer et al.
2013/0064178 A1 3/2013 Cs et al.
2013/0064311 A1 3/2013 Turner et al.
2013/0077664 A1 3/2013 Lee et al.
2013/0080290 A1 3/2013 Kamm
2013/0086639 A1 4/2013 Sondhi et al.
2013/0093638 A1 4/2013 Shoemaker
2013/0108206 A1 5/2013 Sasaoka et al.
2013/0117852 A1 5/2013 Stute
2013/0122828 A1 5/2013 Choi
2013/0124365 A1 5/2013 Pradeep
2013/0127678 A1 5/2013 Chandler
2013/0136410 A1 5/2013 Sasaoka
2013/0144750 A1 6/2013 Brown
2013/0159856 A1 6/2013 Ferren
2013/0160122 A1 6/2013 Choi et al.
2013/0162490 A1 6/2013 Blech
2013/0166690 A1 6/2013 Shatzkamer
2013/0201904 A1 8/2013 Toskala et al.
2013/0207859 A1 8/2013 Legay et al.
2013/0234904 A1 9/2013 Blech
2013/0235845 A1 9/2013 Kovvali et al.
2013/0262656 A1 10/2013 Cao et al.
2013/0262857 A1 10/2013 Neuman et al.
2013/0263263 A1 10/2013 Narkolayev et al.
2013/0279561 A1 10/2013 Jin et al.
2013/0279868 A1 10/2013 Zhang et al.
2013/0305369 A1 11/2013 Karta et al.
2013/0306351 A1 11/2013 Lambert et al.
2013/0311661 A1 11/2013 McPhee
2013/0314182 A1 11/2013 Takeda et al.
2013/0321225 A1 12/2013 Pettus
2013/0326063 A1 12/2013 Burch et al.
2013/0326494 A1 12/2013 Nunez
2013/0330050 A1 12/2013 Yang et al.
2013/0343213 A1 12/2013 Reynolds et al.
2014/0003394 A1 1/2014 Rubin et al.
2014/0003775 A1 1/2014 Ko et al.
2014/0007076 A1 1/2014 Kim et al.
2014/0009270 A1 1/2014 Yamazaki
2014/0009822 A1 1/2014 Dong et al.
2014/0019576 A1 1/2014 Lobo et al.
2014/0028184 A1 1/2014 Voronin et al.
2014/0028190 A1 1/2014 Voronin et al.
2014/0028532 A1 1/2014 Ehrenberg et al.
2014/0032005 A1 1/2014 Iwamura
2014/0043189 A1 2/2014 Lee et al.
2014/0043977 A1 2/2014 Wiley et al.
2014/0044139 A1 2/2014 Dong et al.
2014/0052810 A1 2/2014 Osorio et al.
2014/0071818 A1 3/2014 Wang et al.
2014/0077995 A1 3/2014 Artemenko et al.
2014/0086080 A1 3/2014 Hui et al.
2014/0086152 A1 3/2014 Bontu et al.
2014/0124236 A1 5/2014 Vu et al.
2014/0130111 A1 5/2014 Nulty et al.
2014/0132728 A1 5/2014 Verano et al.
2014/0143055 A1 5/2014 Johnson
2014/0155054 A1 6/2014 Henry et al.
2014/0165145 A1 6/2014 Baentsch et al.
2014/0189677 A1 7/2014 Curzi et al.
2014/0189732 A1 7/2014 Shkedi et al.
2014/0204754 A1 7/2014 Jeong et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2014/0207844	A1	7/2014	Mayo et al.
2014/0208272	A1	7/2014	Vats et al.
2014/0222997	A1	8/2014	Mermoud et al.
2014/0225129	A1	8/2014	Inoue et al.
2014/0227905	A1	8/2014	Knott et al.
2014/0227966	A1	8/2014	Artemenko et al.
2014/0233900	A1	8/2014	Hugonnot et al.
2014/0254979	A1	9/2014	Zhang et al.
2014/0269972	A1	9/2014	Rada et al.
2014/0285293	A1	9/2014	Schuppener et al.
2014/0287702	A1	9/2014	Schuppener et al.
2014/0299349	A1	10/2014	Yamaguchi et al.
2014/0304498	A1	10/2014	Gonuguntla et al.
2014/0317229	A1	10/2014	Hughes et al.
2014/0320364	A1	10/2014	Gu et al.
2014/0334789	A1	11/2014	Matsuo et al.
2014/0351571	A1	11/2014	Jacobs
2014/0355525	A1	12/2014	Barzegar et al.
2014/0355989	A1	12/2014	Finkelstein
2014/0359275	A1	12/2014	Murugesan et al.
2014/0362694	A1	12/2014	Rodrigues
2014/0376655	A1	12/2014	Ruan et al.
2015/0009089	A1	1/2015	Pesa et al.
2015/0017473	A1	1/2015	Verhoeven et al.
2015/0022399	A1	1/2015	Clymer et al.
2015/0026460	A1	1/2015	Walton
2015/0029065	A1	1/2015	Cheng
2015/0036610	A1	2/2015	Kim et al.
2015/0042526	A1	2/2015	Zeine
2015/0061859	A1	3/2015	Matsuoka et al.
2015/0065166	A1	3/2015	Ward et al.
2015/0071594	A1	3/2015	Register
2015/0077740	A1	3/2015	Fuse
2015/0084814	A1	3/2015	Rojanski et al.
2015/0099555	A1	4/2015	Krishnaswamy et al.
2015/0102972	A1	4/2015	Scire-Scappuzzo et al.
2015/0104005	A1	4/2015	Holman
2015/0116154	A1	4/2015	Artemenko
2015/0122886	A1	5/2015	Koch
2015/0138022	A1	5/2015	Takahashi
2015/0156266	A1	6/2015	Gupta
2015/0195349	A1	7/2015	Cardamore
2015/0195719	A1	7/2015	Rahman
2015/0201228	A1	7/2015	Hasek
2015/0215268	A1	7/2015	Dinha

FOREIGN PATENT DOCUMENTS

AU	2010101079	A4	11/2010
AU	201400748		3/2014
AU	2014200748	A1	3/2014
CA	2467988	C	11/2010
CA	2777147	A1	4/2011
CA	2787580	A1	2/2013
CN	1833397	A	9/2006
CN	1885736	A	12/2006
CN	201146495	Y	11/2008
CN	100502181	C	6/2009
CN	201282193	Y	7/2009
CN	101834011	U	4/2010
CN	1823275	B	5/2010
CN	1820482	B	12/2010
CN	102130698	A	7/2011
CN	102136634	A	7/2011
CN	102280704	A	12/2011
CN	202093126	U	12/2011
CN	102351415	A	2/2012
CN	202253536	U	5/2012
CN	102694351	A	9/2012
CN	101662076	B	11/2012
CN	103117118	A	5/2013
CN	103163881	A	6/2013
CN	203204743	U	9/2013
CN	103700442		4/2014
CN	103700442	A	4/2014
CN	103943925	A	7/2014
CN	104052742	A	9/2014
CN	203813973	U	9/2014
CN	104091987	A	10/2014
CN	203931626	U	11/2014
CN	203950607	U	11/2014
DE	202012203816	A1	9/2013
EP	0110478		6/1984
EP	0136818		4/1985
EP	0280379		8/1988
EP	0330303		8/1989
EP	0331248		9/1989
EP	0342149		11/1989
EP	0391719		4/1990
EP	425979	A2	5/1991
EP	0651487		10/1994
EP	0371660		4/1996
EP	0756392		1/1997
EP	0871241	B1	10/1998
EP	0890132		1/1999
EP	755092	A3	4/1999
EP	1085599	A2	3/2001
EP	0756786		8/2001
EP	1127283	A1	8/2001
EP	1129550	A1	9/2001
EP	1376755	A1	1/2002
EP	1184930	A1	3/2002
EP	0772061		7/2003
EP	1346431	A1	9/2003
EP	1249056	B1	1/2004
EP	1401048	A1	3/2004
EP	1488397	A1	12/2004
EP	1371108	B1	6/2005
EP	1550327	A2	7/2005
EP	1341255	B8	8/2005
EP	1624685	A2	2/2006
EP	1642468	A2	4/2006
EP	1608110	B1	10/2006
EP	1898532	A2	3/2008
EP	1930982	A1	6/2008
EP	2165550	A1	3/2010
EP	1166599	B1	5/2010
EP	2404347	A2	1/2012
EP	2568528	A2	3/2013
EP	2472737	B1	9/2013
EP	2854361	A1	4/2015
EP	2870802	A1	5/2015
FR	2691602	A1	11/1993
FR	2849728	A1	7/2004
GB	462804	A	3/1937
GB	529290	A	11/1940
GB	640181	A	7/1950
GB	746111	A	3/1956
GB	751153	A	6/1956
GB	993561	A	5/1965
GB	1076772	A	7/1967
GB	1141390	A	1/1969
GB	1298387	A	11/1972
GB	1383549	A	2/1974
GB	1422956	A	1/1976
GB	2010528	A	6/1979
GB	2045055	A	10/1980
GB	2368468	A	5/2002
GB	2414862	A	12/2005
GB	2411554	B	1/2006
GB	714974		9/2007
GB	2474037	A	4/2011
GB	2485355	A	5/2012
GB	2507269	A	4/2014
JP	61260702	A	11/1986
JP	03167906	A	7/1991
JP	0653894		8/1991
JP	3001844	U	9/1994
JP	08196022	A	7/1996
JP	08316918	A	11/1996
JP	2639531	B2	8/1997
JP	11239085	A	8/1999
JP	11313022	A	11/1999

(56) **References Cited**

FOREIGN PATENT DOCUMENTS

JP	2000077889	A	3/2000
JP	2002029247	A	1/2002
JP	3480153	B2	12/2003
JP	2004253953	A	9/2004
JP	2006153878	A	6/2006
JP	2006166399	A	6/2006
JP	2008021483	A	1/2008
JP	4072280	B2	4/2008
JP	2009004986	A	1/2009
JP	2009124229	A	6/2009
JP	2012090242	A	5/2012
JP	2012205104	A	10/2012
JP	2013046412	A	3/2013
JP	2013110503	A	6/2013
JP	2014045237	A	3/2014
JP	5475475	B2	4/2014
JP	5497348	B2	5/2014
KR	20000074034		12/2000
KR	200425873	Y1	9/2006
KR	101070364	B1	9/2011
KR	101212354	B1	12/2012
KR	20140104097	A	8/2014
RU	2129746	C1	4/1999
WO	8301711	A1	5/1983
WO	9210014		6/1992
WO	9323928		11/1993
WO	9529537	A1	11/1995
WO	9735387	A1	9/1997
WO	9737445	A1	10/1997
WO	9948230	A1	9/1999
WO	9967903	A1	12/1999
WO	0070891	A1	11/2000
WO	00/74428	A1	12/2000
WO	WO0114985	A1	3/2001
WO	0145206	A1	6/2001
WO	02061467	A2	8/2002
WO	03088418		10/2003
WO	03099740	A1	12/2003
WO	2004011995	A1	2/2004
WO	2004038891	A2	5/2004
WO	2004/051804		6/2004
WO	2004051804	A1	6/2004
WO	2004077746	A1	9/2004
WO	2006012610	A2	2/2006
WO	2006085804	A1	8/2006
WO	2006116396	A2	11/2006
WO	2006125279	A1	11/2006
WO	2006050331	A3	3/2007
WO	2007031435	A1	3/2007
WO	2007071797	A1	6/2007
WO	2008003939	A1	1/2008
WO	2008070957	A1	6/2008
WO	2008117973	A1	10/2008
WO	2009014704	A1	1/2009
WO	2007098061	A3	2/2009
WO	2009035285	A2	3/2009
WO	2010147806	A1	12/2010
WO	2011137793	A1	11/2011
WO	2012/007831		1/2012
WO	2012038816	A1	3/2012
WO	2012172565	A1	12/2012
WO	2013013162	A2	1/2013
WO	2013035110	A2	3/2013
WO	2013/073548		5/2013
WO	2013073548	A1	5/2013
WO	2013100912	A1	7/2013
WO	2013115802	A1	8/2013
WO	2013123445	A1	8/2013
WO	2013/138627		9/2013
WO	2014/045236		9/2013
WO	2013136213	A1	9/2013
WO	2013138627	A1	9/2013
WO	2013157978	A1	10/2013
WO	2014/018434		1/2014
WO	2014018434	A2	1/2014
WO	2014065952	A1	5/2014
WO	2014099340	A2	6/2014
WO	2013076499	A3	7/2014
WO	2014128253	A1	8/2014
WO	2014145862	A2	9/2014
WO	2014197926	A1	12/2014
WO	2015002658	A1	1/2015
WO	2015006636	A1	1/2015
WO	2015027033	A1	2/2015
WO	2015035463	A1	3/2015
WO	2015052478		4/2015
WO	2015052480		4/2015
WO	2015069431	A2	5/2015
WO	2015077644		5/2015

OTHER PUBLICATIONS

"Cisco IP VSAT Satellite WAN Network Module for Cisco Integrated Services Routers", http://www.cisco.com/c/en/us/products/collateral/interfaces-modules/ip-vsatsatellite-wan-module/product_data_sheet0900aecd804bbf6f.html, Jul. 23, 2014.

"Exacter Outage-Avoidance System", http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001020393, Nov. 30, 2009.

"Ipitek All-Optical Sensors", http://www.ipitek.com/solutions-by-industry/all-optical-sensors; Jun. 2, 2014.

"RF Sensor Node Development Platform for 6LoWPAN and 2.4 GHz Applications", http://www.ti.com/tool/TIDM-RF-SENSORNODE, Jun. 2, 2014.

"Wireless powerline sensor", wikipedia.org, http://en.wikipedia.org/wiki/Wireless_powerline_sensor, 2014, 3 pages.

Bach, Christian, "Current Sensor—Power Line Monitoring for Energy Demand Control", Application Note 308, http://www.enocean.com/fileadmin/redaktion/pdf/app_notes/AN308_Current_Sensor_Jan09.pdf, Jan. 2009, 4 pages.

Chiba, Jiro, "Experimental Studies of the Losses and Radiations Due to Bends in the Goubau Line", IEEE Transactions on Microwave Theory and Techniques, Feb. 1977, 94-100.

Chiba, Jiro, "On the Equivalent Circuit for the G-Line Above Ground", International Wroclaw Symposium on Electromagnetic Compatibility, 1998, 78-82.

Elmore, Glenn, "Introduction to the Propagating Wave on a Single Conductor", www.corridor.biz, Jul. 27, 2009, 30 pages.

Friedman, M. et al., "Low-Loss RF Transport Over Long Distances", IEEE Transactions on Microwave Theory an Techniques, vol. 49, No. 2, Feb. 2001, 341-348.

Izumiyama, Hidetaka et al., "Multicast over satellite", Applications and the Internet, 2002.(SAINT 2002). Proceedings. 2002 Symposium on. IEEE, 2002.

Jawhar, Imad et al., "A hierarchical and topological classification of linear sensor networks", Wireless Telecommunications Symposium, WTS, IEEE, http://faculty.uaeu.ac.ae/Nader_M/papers/WTS2009.pdf, 2009, 8 pages.

Jee, George et al., "Demonstration of the Technical Viability of PLC Systems on Medium- and Low-Voltage Lines in the United States", Broadband is Power: Internet Access Via Power Line Networks, IEEE Communication Magazine, May 2003, 5 pages.

Kuhn, Marc et al., "Power Line Enhanced Cooperative Wireless Communications", IEEE Journal on Selected Areas in Communications, vol. 24, No. 7, Jul. 2006, 10 pages.

Patel, Shwetak N. et al., "The Design and Evaluation of an End-User-Deployable, Whole House, Contactless Power Consumption Sensor", CHI 2010: Domestic Life, Apr. 2010, 10 pages.

Rappaport, Theodore S. et al., "Mobile's Millimeter-Wave Makeover", Spectrum.IEEE.Org; Sep. 2014.

Sagar, Nishant , "Powerline Communications Systems: Overview and Analysis", Thesis, May 2011, 80 pages.

Sarafi, Angeliki M. et al., "Hybrid Wireless-Broadband over Power Lines: A Promising Broadband Solution in Rural Areas", IEEE Communications Magazine, Nov. 2009, 8 pages.

Sommerfeld, A. , "On the propagation of electrodynamic waves along a wire", Annals of Physics and Chemistry New Edition, vol. 67, No. 2, 1899, 72 pages.

(56) **References Cited**

OTHER PUBLICATIONS

Yang, "Power Line Sensor Networks for Enhancing Power Line Reliability and Utilization", Georgia Institute of Technology, https://smartech.gatech.edu/bitstream/handle/1853/41087/Yang_Yi_201108_phd.pdf, Apr. 26, 2011, 264 pages.

Yang, et al., "Power line sensornet—a new concept for power grid monitoring", IEEE Power Engineering Society General Meeting, 2006, pp. 8.

Zhao, et al., "Energy harvesting for a wireless-monitoring system of overhead high-voltage power lines", IET Generation, Transmission & Distribution 7, IEEE Xplore Abstract, 2013, 2 pages.

Alam, M N et al., "Novel surface wave exciters for power line fault detection and communications", Antennas and Propagation (APSURSI), 2011 IEEE International Symposium on, IEEE, Jul. 3, 2011. pp. 1139-1142.

Doelitzscher, et al., "ViteraaS: Virtual cluster as a service." Cloud Computing Technology and Science (CloudCom), 2011 IEEE Third International Conference on. IEEE, 2011.

Golrezaei, Negin et al., "FemtoCaching: Wireless Video Content Delivery through Distributed Caching Helpers", INFOCOM, 2012 Proceedings IEEE.

Gritzalis, Dimitris et al., "The Sphinx enigma in critical VoIP infrastructures: Human or botnet?." Information, Intelligence, Systems and Applications (IISA), 2013 Fourth International Conference, IEEE, 2013.

Hautakorpi, Jani et al., "Requirements from Session Initiation Protocol (SIP) Session Border Control (SBC) Deployments." RFC5853, IETF (2010).

Hawrylyshen, A. et al., "SIPPING Working Group J. Hautakorpi, Ed. Internet-Draft G. Camarillo Intended status: Informational Ericsson Expires: Dec. 18, 2008 R. Penfield Acme Packet." (2008).

Jin, Yu et al., "Nevermind, the Problem is Already Fixed: Proactively Detecting and Troubleshooting Customer DSL Problems", ACM CoNEXT, Philadelphia, USA, Nov.-Dec. 2010, 12 pages.

Kamilaris, et al., "Exploring the Use of DNS as a Search Engine for the Web of Things." Internet of Things (WF-IoT), 2014 IEEE World Forum on. IEEE, 2014.

Mokhtarian, Kianoosh et al., "Caching in Video CDNs: Building Strong Lines of Defense", EuroSys 2014, Apr. 13-16, 2014, Amsterdam, Netherlands.

Paul, Sanjoy et al., "The Cache-and-Forward Network Architecture for Efficient Mobile Content Delivery Services in the Future Internet", Innovations in NGN: Future Network and Services, 2008. K-INGN 2008. First ITU-T Kaleidoscope Academic Conference.

"24 Volt D.C Flashing Light With Built-in Antenna 433Mhz, DEA+ Product Guide" Meteor electrical, meteorelectrical.com, Code: LUMY/24A, Jul. 28, 2010.

"An Improved Solid Dielectric Lens Impulse Radiating Antenna," SBIR/STTR, DoD, sbir.gov, 2004.

"Boost: The world's first WI-FI extending led bulb," Sengled, sengled.com, Dec. 2014 http://www.sengled.com/sites/default/files/field/product/downloads/manual/a01-a60_na_user_manual_20141223.pdf.

"Cband & L/Sband Telemetry Horn Antennas," mWAVE, mwavellc.com, Jul. 6, 2012, http://www.mwavellc.com/custom -Band-Ls--BandTelemetryHornAntennas.php.

"Dielectric Antenna," Microwave Technologies, Ind., microwavetechnologiesinc.co.in http://www.microwavetechnologiesinc.co.in/microwavecommunicationlabproducts.html#dielectricantenna, May 21, 2015.

"Examples of Cell Antennas," RF Check®, rfcheck.com, Feb. 1, 2010 https://web.archive.org/web/20100201214318/http://www.rfcheck.com/Examplesof-Cell-Antennas.php.

"Flashing Light : IR.Lamp," Beninca®, beninca.com, Feb. 23, 2015. http://www.beninca.com/en/news/2015/02/23/lampeggiante-irlamp.html.

"Horn Antennas," Steatite QPar Antennas, steatiteqparantennas.co.uk, http://www.steatiteqparantennas.co.uk/products hornantennas.html? http://www.steatiteqparantennas.co.uk/consultancy/customhornantennas/, May 21, 2015.

"How is ELine Different?," ELine Corridor Systems, corridor.biz http://www.corridor.biz/ELine_is_different.html, Apr. 23, 2015.

"Identity Management," Tuomas Aura CSE-C3400 Information Security, Aalto University, Autumn 2014, 33 pgs.

"Integrated Radio Masts Fully camouflaged Outdoor-Wi-Fi APs in GRP-lamp poles," Brown-iposs, brown-iposs.com, Mar. 21, 2014.

"New Wi-Fi antenna enhances wireless coverage," ScienceDaily®, sciencedaily.com, May 29, 2015.

"Power Communication," Communication Power Solutions, Inc., cpspower.biz, http://www.cpspower.biz/services/powercommunications/, Oct. 2013.

"Power Line Communications," Atmel®, atmel.com http://www.atmel.com/products/smartenergy/powerlinecommunications/default.aspx, 2015.

"Power line communications: An overview Part I." King Fand University of Petroleum and Minerals, Dhahran, KSA, 2008.

"Powerline Communication," Cypress Perform, cypress.com http://www.cypress.com/?id=2330, Apr. 23, 2015.

"Products: GSM Mircro Repeater." L-TEL: Quanzhou L-TEL Communication Equipment Co., LTD., I-tel.com, Apr. 24, 2015.

"Waveguide-fed Conical Horn," Antenna Magus, antennamagus.com, © 2015, accessed: Aug. 2015.

"Product Abstract—Program on Technology Innovation: Study on the Integration of High Temperature Superconducting DC Cables Within the Eastern and West urn North American Power Grids." EPRI—Electronic Power Research Institute, epri.com, Product ID:10203, Nov. 25, 2009.

"A Dielectric Lens Antenna with Enhanced Aperture Efficiency for Industrial Radar Applications", Computer Simulation Technology, cst.com, May 10, 2011.

"About Firelight Media Group", http://www. insu ra ncetechnologies.com/Products/Prod ucts_firelight_overview .s html, Firelight®. Insurance Technologies, LLC,, Apr. 19, 2015.

"Asahi Multi-Core Fiber Cable", Industrial Fiber optics, i-fiberoptics.com http://i-fiberoptics.com/m u iti-core-fi ber-ca ble. ph p, Apr. 26, 2015.

"Bi-Axial PA Horn with Gimbal Mount", Atlas Sound, MCM Electronics, mcmelectronics.com, MCM Part #555-13580, 2011.

"Broadband Negligible Loss Metamaterials", Computer Electmagnetics and Antennas Research Laboratory, cearl.ee.psu.edu, May 15, 2012.

"Cloud Management", Cisco Meraki, cisco.com, Sep. 11, 2015.

"Decryption: Identify & Control Encrypted Traffic", Palo Alto Networks, paloaltonetworks.com, Mar. 7, 2011.

"Denso", Winn & Coales (Denso) Ltd. UK, denso.net, http://www.denso.net/voidfiller/voidpump.htm, 2015, 1 page.

"Detecting and Preventing MAC Spoofing", Detecting and Preventing MAC Spoofing | Network Access Control Solutions, infoexpress, 2014.

"Electronic Business Fulfillment FireLight ®", Firelight Media Group LLC, firelightmedia.net http://www .firelightmedia .net/fmg/index.php/home, Apr. 19, 2015, 2 pages.

"Elliptical Polarization", "Elliptical Polarization" Wikipedia, <http://en.wikipedia.org/wiki/Elliptical_polarization>, Apr. 21, 2015, 3 pgs.

"GM-12 Gimbal Mount", Newmark System, Inc, newmarksystems.com, 2015.

"HiveManager Network Management System", Aerohive® Networks, aerohive.com, accessed: Sep. 2015.

"Home", Darktrace, darktrace.com, Jul. 10, 2014.

"How to Use STUF", STUF Page Link Info, crossdevices.com, http://www.crossdevices.com/cross_devices 010.htm, 2015, 1 page.

"Installing Satellite Accessories", ACE®, acehardware.com, Aug. 5, 2006.

"mmWave Axial Choke Horn Antenna with Lens", Feko, Sep. 24, 2013.

"Network technology", nbnTM, nbnco.com.au, Jun. 27, 2014.

"Norse Appliance™: Block attacks before they target your network, and dramatically improve the ROI on your entire security infrastructure", norsecorp.com, 2015.

"Out-of-Band Mgmt", Cradle Point, cradlepoint.com, accessed: Sep. 2015.

(56) **References Cited**

OTHER PUBLICATIONS

"Out-of-Band Security Solution", Gigamon®, gigamon.com, Aug. 3, 2014.
"Powerline—Juice Up Your Network With Powerline", Netgear®, netgear.com http://www.netgear.com/home/products/networking/powerline/, Apr. 21, 2015, 3 pages.
"Pro 600 Sirius XM Radio Amplified Outdoor Antenna", Pixel Technologies, Oct. 3, 2014.
"Product Overview: Introducing SilentDefense", Security Matters, secmatters.com, Nov. 9, 2013.
"Quickly identify malicious traffics: Detect", Lancope®, lancope.com, Mar. 15, 2015.
"radar at st Andrews", mmwaves.epr, st-andrews.ac.uk, Feb. 4, 2011.
"Resilience to Smart Meter Disconnect Attacks", ADSC Illinois at Singapore PTE, LTD., publish.illinois.edu http://publish.illinois.edu/integrativesecurityassessment/resiliencetosmartmeterdisconnectattacks/, 2015.
"Smart Out-of-Band Management", Open Gear, opengear.com, accessed: Sep. 2015.
"Tapered waveguide", Lumerical Solutions, Inc., docs lumerical.com, 2010.
"Tapered Waveguides Improve Fiber Light Coupling Efficiency", Tech Briefs, techbriefs.com, Jan. 1, 2006, Molex Inc., Downers Grove, Illinois and KiloLambda Technologies Ltd., Tel Aviv, Israel.
Akiba, Shigeyuki et al., "Photonic Architecture for Beam Forming of RF Phased Array Antenna", Optical Fiber Communication Conference Optical Society of America, 2014.
Alam, M.N. et al., "Novel surface wave exciters for power line fault detection and communications." Antennas and Propagation (APSURSI), 2011 IEEE International Symposium on. IEEE, 2011.
Ali, Muhammad Q. et al., "Randomizing AMI configuration for proactive defense in smart grid", Smart Grid Communications (SmartGridComm), 2013 IEEE International Conference on. IEEE, http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=6688027, 2013.
Angove, Alex , "Direct Bury Duct Assemblies, MPB 302 3+- Ribbonet Microducts", Ericsson, archive.ericsson.net, Jul. 30, 2014.
Angove, Alex , "How the NDN Differs from ADSL2+, Cable and Wireless", Whistle Out, whistleout.com.au, Jul. 30, 2014.
Arage, Alebel et al., "Measurement of wet antenna effects on millimetre wave propagation", Radar, 2006 IEEE Conference on IEEE, 2006.
Arthur, Joseph Kweku , "Improving QoS in UMTS Network in ACCRA Business District Using Tower-Less Towers", IPASJ International Journal of Electrical Engineering (IIJEE), vol. 2, Issue 11, Nov. 2014.
Asadallahi, Sina et al., "Performance comparison of CSMA/CA Advanced Infrared (ALR) and a new pointtomultipoint optical MAC protocol." Wireless Communications and Mobile Computing Conference(IWCMC), 2012 8th International. IEEE, 2012.
Atwater, Harry A. , "The promise of plasmonics." Scientific American 296.4 (2007): 56-62.
Barron, Ashleigh L. , "Integrated Multicore Fibre Devices for Optical Trapping", Diss. Heriot-Watt University, 2014, 11-15.
Beal, J.C. et al., "Coaxial-slot surface-wave launcher", Electronics Letters 4.25 (1968): 557559.
Bhushan, Naga , "Network densification: the dominant theme for wireless evolution into 5G", Communications Magazine, IEEE 52.2 (2014): 82-89.
Bing, Benny , "Ubiquitous Broadband Access Networks with Peer-to-Peer Application Support", Evolving the Access Network, 2006, 27-36.
Bock, James et al., "Optical coupling." Journal of Physics: Conference Series. vol. 155. No. 1.1OP Publishing, 2009.
Bowen, Leland H. et al., "A Solid Dielectric Lens Impulse Radiating Antenna with High Dielectric Constant Surrounded by a Cylindrical Shroud," Sensor and Simulation Note 498, Apr. 2005.
Bridges, Greg E. et al., "Plane wave coupling to multiple conductor transmission lines above a lossy earth", Compatibility, IEEE Transactions on 31.1, 1989, 21-33.
Brooke, Gary H. , Properties of surface waveguides with discontinuities and perturbations in cross-section. Diss. University of British Columbia, 1977.
Brown, J. et al., "The launching of radial cylindrical surface waves by a circumferential slot", Proceedings of the IEE Part B: Radio and Electronic Engineering 106.26 (1959): 123128.
Bruno, Joseph , "Interference Reduction in Wireless Networks", Computing Research Topics, Computing Sciences Department, Villanova University, Nov. 14, 2007, 8 pages.
Burkhart, Martin et al., "Does Topology Control Reduce Interference?", Department of Computer Science, ETH Zurich, Proceedings of the 5th ACM international symposium on Mobile ad hoc networking and computing, ACM, 2004, 11 pages.
Callis, et al., "An In-Line Power Monitor for HE11 Low Loss Transmission Lines", Proceedings of the 29th International Conference on Infrared and Millimeter Waves (IRMMW), Karlsruhe, Germany, 2004.
Carroll, John M. et al., "Developing the Blacksburg electronic village", Communications of the ACM 39.12 (1996): 69-74.
Chen, Dong et al., "A trust management model based on fuzzy reputation for internet of things", Computer Science and Information Systems 8.4 (2011): 12071228.
Chen, Yingying , "Detecting and Localizing Wireless Spoofing Attacks", Sensor, Mesh and Ad Hoc Communications and Networks, 2007, SECON'07. 4th Annual IEEE Communications Society Conference on IEEE, 2007, 10 pages.
Cimini, Carlos Alberto et al., "Temperature profile of progressive damaged overhead electrical conductors", Journal of Electrical Power & Energy Systems 49 (2013): 280-286.
Costantine, Joseph et al., "The analysis of a reconfigurable antenna with a rotating feed using graph models", Antennas and Wireless Propagation Letters 8 (2009): 943-946.
Covington, Michael J. et al., "Threat implications of the internet of things", Cyber Conflict (CyCon), 2013 5th International Conference on. IEEE, 2013.
Crane, Robert K. , "Analysis of the effects of water on the ACTS propagation terminal antenna", Antennas and Propagation, IEEE Transactions on 50.7 (2002): 954965.
De Sabata, Aldo et al., "Universitatea Politehnica", din Timi Ş oara Facultatea de Electronică § Ş i Telecomunica ţ ii, 2012.
Dini, Gianluca et al., "MADAM: A Multilevel Anomaly Detector for Android Malware", MMMACNS. vol. 12, 2012.
Doane, J.L. et al., "Oversized rectangular waveguides with modefree bends and twists for broadband applications", Microwave Journal 32(3), 1989, 153-160.
Dooley, Kevin , "Out-of-Band Management", auvik, auvik.com, May 12, 2014.
Dostert, Klaus , "Frequency-hopping spread-spectrum modulation for digital communications over electrical power lines." Selected Areas in Communications, IEEE Journal on 8.4 (1990): 700-710.
Dragoo, R.E. et al., "Fiber Optic Data Bus for the AN/GYQ21(V)." Harris Corp, U.S. Communications Syst. Div. Chart, Microcopy Resolution Test, 1980.
Dutton, Harry Jr. , "Understanding Optical Communications", International Technical Support Organization, SG24-5230-00, Sep. 1998.
Ehyaie, Danial , "Novel Approaches to the Design of Phased Array Antennas," Diss. The University of Michigan, 2011.
Erickson, Katherine , "Conductive cylindrical surface waveguides." (2012) https://www.ideals.illinois.edu/bitstream/handle/2142/30914/Erickson_Katherine.pdf?sequence=1.
Eskelinen, Harri , "DFM (A)—aspects for a horn antenna design," Lappeenranta University of Technology, 2004.
Eskelinen, P. , "A low-cost microwave rotary joint," International Radar Conference, Oct. 13-17, 2014, p. 1-4.
Feng, Taiming et al., "Design of a survivable hybrid wireless-optical broadband-access network", Journal of Optical Communications and Networking 3.5, 2011, 458-464.
Fenye, Bao et al., "Dynamic trust management for internet of things applications", Proceedings of the 2012 international workshop on Selfaware internet of things. ACM, 2012.
Freyer, Dan , "Combating the Challenges of Ka-Band Signal Degradation", SatMagazine, satmagzine.com, Sep. 2014.

(56) **References Cited**

OTHER PUBLICATIONS

Fromm, W. et al., "A new microwave rotary joint," 1958 IRE International Convention Record, Mar. 21-25 1966, 6:78-82.
Garcia-Etxarri, Aitzol et al., "A combination of concave/convex surfaces for fieldenhancement optimization: the indented nanocone", Optics express 20.23, 2012, 2520125212.
Ghazisaidi, Navid et al., "Survivability analysis of next-generation passive optical networks and fiber-wireless access networks", Reliability, IEEE Transactions on 60.2, 2011, 479-492.
Gomes, Nathan J. et al., "Radio-over-fiber transport for the support of wireless broadband services", Journal of Optical Networking 8.2 (2009): 156-178.
Gonthier, François et al., "Mode coupling in nonuniform fibers: comparison between coupled-mode theory and finite-difference beam-propagation method simulations", Josa B 8.2 (1991): 416421.
Han, Chong et al., "crosslayer communication module for the Internet of Things", Computer Networks 57.3 (2013): 622633.
Haroun, Ibrahim et al., "WLANs meet fiber optics-Evaluating 802. 11. a WLANs over fiber optics links", RF Des. Mag (2003): 36-39.
Hassan, Karim , "Fabrication and characterization of thermo-plasmonic routers for telecom applications", Diss. Univ. de Bourgogne, 2014.
Hassan, Maaly A. , "Interference reduction in mobile ad hoc and sensor networks", Journal of Engineering and Computer Innovations vol.2(7), Sep. 2011, 138-154.
Hassani, Alireza et al., "Porous polymer fibers for low-loss Terahertz guiding." Optics express 16.9 (2008): 6340-6351.
Hoss, R.J. et al., "Manufacturing Methods and Technology Program for Ruggedized Tactical Fiber Optic Cable", No. ITT-80-03-078. ITT Electrooptical Products DIV Roanoke Va, 1980.
Ippolito, Louis J. , "Propagation effects handbook for satellite systems design. A summary of propagation impairments on 10 to 100 GHz satellite links with techniques for system design", 1989.
Jackson, Mark , "Timico CTO Hit by Slow FTTC Broadband Speeds After Copper Corrosion", ISP review, ispreview.co.uk, Mar. 5, 2013.
Jaeger, Raymond et al., "Radiation Performance of Germanium Phosphosilicate Optical Fibers." RADC-TR-81-69: Final Technical Report, Galileo Electro-Optical Corp, (May 1981).
James, J.R. et al., "Investigations and Comparisons of New Types of Millimetre-Wave Planar Arrays Using Microstrip and Dielectric Structures", Royal Military Coll of Science Shrivenham (England), 1985.
Jang, Hung-Chin , "Applications of Geometric Algorithms to Reduce Interference in Wireless Mesh Network", Journal on Applications of Graph Theory in Wireless Ad hoc Networks and Sensor Networks (JGRAPH-HOC) vol. 2, No. 1, Mar. 2010.
Jeong, et al., "Study of elliptical polarization requirement of KSTAR 84-GHz ECH system", Journal-Korean Physical Society 49, 2006.
Jin, , "Quasi-optical mode converter for a coaxial cavity gyrotron", Forschungszentrum, 2007.
Kang, , "Chapter 6: Array Antennas," IHS Engineering360, globalspec.com, http://www.globalspec.com/reference/75109/203279/chapter-6-array-antennas, Apr. 22, 2015.
Katkovnik, Vladimir et al., "High-resolution signal processing for a switch antenna array FMCW radar with a single channel receiver", Sensor Array and Multichannel Signal Processing Workshop Proceedings, 2002. IEEE, 2002.
Khan, , "Dual polarized dielectric resonator antennas", Chalmers University of Technology, 2010.
Kikuchi, H. et al., "Hybrid transmission mode of Goubau lines",J. Inst.Electr.Comm.Engrs., Japan,vol. 43, pp. 39-45,1960.
Kirkham, H. et al., "Power system applications of fiber optics (Jet Propulsion Lab." JPL Publication 84-28, Electric Energy Systems Division, U.S. DoE, p. 180, (1984).
Koshiba, Masanori et al., "Analytical expression of average power-coupling coefficients for estimating intercore crosstalk in multicore fibers", Photonics Journal, IEEE 4.5, 2012, 1987-1995.
Kroon, Barnard et al., "Steady state RF fingerprinting for identity verification: one class classifier versus customized ensemble." Artificial Intelligence and Cognitive Science. Springer Berlin Heidelberg, 2010. 198206.
Kroyer, Thomas , "A Waveguide High Order Mode Reflectometer for the Large Hadron Collider Beam-pipe", Diss. Tu Wien, 2003.
Kumar, Sailesh , "Survey of Current Network Intrusion Detection Techniques", Washington Univ. in St. Louis, Dec. 2007.
Lappgroupusa, "Selection of Number of Cable Cores With Emphasis on Sizing Parameters", Industrial Cable & Connector Technology News, lappconnect.blogspot.com, http://lappconnect.blogspot.com/2014_10_01_archive.html, Oct. 30, 2014.
Leech, Jamie et al., "Experimental investigation of a low-cost, high performance focal-plane horn array." Terahertz Science and Technology, IEEE Transactions on 2.1 (2012): 61-70.
Li, Xiang-Yang et al., "Interference-Aware Topology Control for Wireless Sensor Networks", SECON. vol. 5, 2005.
Li, Xiaowei et al., "Integrated plasmonic semi-circular launcher for dielectric-loaded surface plasmonpolariton waveguide", Optics express 19.7 (2011): 65416548.
Li, Xu et al., "Smart community: an internet of things application", Communications Magazine, IEEE 49.11 (2011): 68-75.
Lier, E. et al., "Simple hybrid mode horn feed loaded with a dielectric cone," Electronics Letters 21.13 (1985): 563564.
Lim, Christina et al., "Fiber-wireless networks and subsystem technologies", Lightwave Technology, Journal of 28.4 (2010): 390-405.
Lou, Tiancheng , "Minimizing Average Interference through Topology Control", Algorithms for Sensor Systems, Springer Berlin Heidelberg, 2012, 115-129.
Lucyszyn, S. et al., "Novel RF MEMS Switches", Microwave Conference, 2007. APMC 2007. Asia-Pacific. IEEE, 2007.
Lucyszyn, Stepan et al., "RF MEMS for antenna applications", Antennas and Propagation (EuCAP), 2013 7th European Conference on. IEEE, 2013.
Luo, Qi et al., "Circularly polarized antennas", John Wiley & Sons, 2013.
Mahato, Suvranshu Sekhar , Studies on an Infrared Sensor Based Wireless Mesh Network. Diss. 2010.
Maier, Martin et al., "The audacity of fiberwireless (FiWi) networks", AccessNets. Springer Berlin Heidelberg, 2009. 16-35.
Marcatili, E.A. et al., "Hollow Metallic and Dielectric Waveguides for Long Distance Optical Transmission and Lasers", Bell System Technical Journal 43(4), 1964, 1783-1809.
McAllister, M.W. et al., "Resonant hemispherical dielectric antenna," Electronics Letters 20.16 (1984): 657659.
Meng, H. et al., "A transmission line model for high-frequency power line communication channel", Power System Technology, PowerCon 2002. International Conference on. vol. 2. IEEE, 2002. http://infocom. uniroma 1.it/ enzobac/MengChen02. pdf, 2002.
Menon, S.S. et al., "Propagation characteristics of guided modes in a solid dielectric pyramidal horn," Proceedings of the 2012 International Conference on Communication Systems and Network Technologies. IEEE Computer Society, 2012.
Mitchell, John E. , "Integrated Wireless Backhaul Over Optical Access Networks", Journal of Lightwave Technology 32.20, 2014, 3373-3382.
Miyagi, M. , "Bending losses in hollow and dielectric tube leaky waveguides", Applied Optics 20(7), 1981, 1221-1229.
Moaveni-Nejad, Kousha et al., "Low-Interference Topology Control for Wireless Ad Hoc Networks", Department of Computer Science, Illinois Institute of Technology, Ad Hoc & Sensor Wireless Networks 1.1-2, 2005, 41-64.
Moisan, M. et al., "Plasma sources based on the propagation of electromagnetic surface waves", Journal of Physics D: Applied Physics 24.7 (1991): 1025.
Morse, T.F. , "Research Support for the Laboratory for Lightwave Technology." Brown Univ Providence RI Div of Engineering, 1992.
Mruk, Joseph Rene , "Wideband monolithically integrated frontend subsystems and components", Diss. University of Colorado, 2011.
Nachiketh, P. et al., "Optimizing public-key encryption for wireless clients", Proceedings of the IEEE International Conference on Communications (ICC 2002). No. 1. 2002.

(56) **References Cited**

OTHER PUBLICATIONS

Narayanan, Arvind , "Fingerprinting of RFID Tags and HighTech Stalking." 33 Bits of Entropy, 33bits.org, Oct. 4, 2011.
Nassa, Vinay Kumar , "Wireless Communications: Past, Present and Future", Dronacharya Research Journal: 50. vol. III, Issue-II, Jul.-Dec. 2011.
Nibarger, John P. , "An 84 pixel all-silicon corrugated feedhorn for CMB measurements." Journal of Low Temperature Physics 167.3-4 (2012): 522-527.
Nicholson, Basil J. , "Microwave Rotary Joints for X-, C-, and S-band", Battelle Memorial Inst Columbus OH, 1965.
Nuvotronics, , "PolyStrata—Phased Arrays & Antennas", Nuvotronics, nuvotronics.com http://www.nuvotronics.com/antennas.php, Apr. 26, 2015.
Olver, A. D. , "Microwave horns and feeds," vol. 39. IET, 1994.
Olver, A.D. et al., "Dielectric cone loaded horn antennas," Microwaves, Antennas and Propagation, IEE Proceedings H. vol. 135. No. 3. IET, 1988.
Orfanidis, Sophocles J. , "Electromagnetic waves and antennas," Rutgers University, 2002.
Pahlavan, Kaveh et al., "Wireless data communications", Proceedings of the IEEE 82.9 (1994): 1398-1430.
Perkons, Alfred R. et al., "TM surface-wave power combining by a planar active-lens amplifier", Microwave Theory and Techniques, IEEE Transactions on 46.6 (1998): 775783.
Péter, Zsolt et al., "Assessment of the current intensity for preventing ice accretion on overhead conductors", Power Delivery, IEEE Transactions on 22.1 (2007): 565-574.
Petrovsky, Oleg , "The Internet of Things: A Security Overview", w.druva.com, Mar. 31, 2015.
Pham, Tien-Thang et al., "A WDM-PON-compatible system for simultaneous distribution of gigabit baseband and wireless ultrawideband services with flexible bandwidth allocation", Photonics Journal, IEEE 3.1, 2011, 13-19.
Piksa, Petr et al., "Elliptic and hyperbolic dielectric lens antennas in mmwaves", Radioengineering 20.1, 2011, 271.
Plagemann, Thomas et al., "Infrastructures for community networks", Content Delivery Networks. Springer Berlin Heidelberg, 2008. 367-388.
Pohl, , "A dielectric lens-based antenna concept for high-precision industrial radar measurements at 24GHz," Radar Conference (EuRAD), 2012 9th European, IEEE, 2012.
Pranonsatit, S. et al., "Sectorised horn antenna array using an RF MEMS rotary switch", Asia-Pacific Microwave Conf., APMC. 2010.
Pranonsatit, Suneat et al., "Single-pole eight-throw RF MEMS rotary switch", Microelectromechanical Systems, Journal of 15.6 (2006): 1735-1744.
Prashant, R.R. et al., "Detecting and Identifying the Location of Multiple Spoofing Adversaries in Wireless Network", International Journal of Computer Science and Mobile Applications, vol. 2 Issue. 5, May 2014, 1-6.
Rahim, S. K. A. et al., "Measurement of wet antenna losses on 26 GHz terrestrial microwave link in Malaysia", Wireless Personal Communications 64.2 (2012): 225231.
Rambabu, K. et al., "Compact single-channel rotary joint using ridged waveguide sections for phase adjustment," IEEE Transactions on Microwave Theory and Techniques (Aug. 2003) 51(8):1982-1986.
Raychaudhuri, Dipankar et al., "Emerging Wireless Technologies and the Future Mobile Internet", Cambridge University Press, Mar. 2011.
Raychem, "Wire and Cable", Dimensions 2 (1996): 1.
Reynet, Olivier et al., "Effect of the magnetic properties of the inclusions on the high-frequency dielectric response of diluted composites." Physical Review B66.9 (2002): 094412.
Rouse, Margaret , "Transport Layer Security (TLS)", TechTarget, searchsecurity.techtarget.com, Jul. 2006.
Roze, Mathieu et al., "Suspended core subwavelength fibers: towards practical designs for low-loss terahertz guidance." Optics express 19.10 (2011): 9127-9138.
Sagues, Mikel et al., "Multi-tap complex-coefficient incoherent microwave photonic filters based on optical single-sideband modulation and narrow band optical filtering." Optics express 16.1 (2008): 295-303.
Saied, Yosra Ben et al., "Trust management system design for the internet of things: a contextaware and multiservice approach", Computers & Security 39 (2013): 351365.
Salema, Carlos et al., "Solid dielectric horn antennas," Artech House Publishers, 1998.
Sarafi, A. et al., "Hybrid wireless-broadband over power lines: A promising broadband solution in rural areas." Communications Magazine, IEEE 47.11 (2009): 140-147.
Sarnecki, Joseph et al., "Microcell design principles", Communications Magazine, IEEE 31.4 (1993): 76-82.
Saruhan, Ibrahim Halil , "Detecting and Preventing Rogue Devices on the Network", SANS Institute InfoSec Reading Room, sans.org, Aug. 8, 2007.
Scarfone, Karen et al., "Technical Guide to Information Security Testing and Assessment", National Institute of Standards and Technology, csrc.nist.gov, Special Publication, Sep. 2008, 800-115.
Shafai, Lotfollah , "Dielectric Loaded Antennas", John Wiley & Sons, Inc., http://www.researchgate.net/publication/227998803_Dielectric_Loaded_Antennas, Apr. 15, 2005.
Shafi, Mansoor et al., "Advances in Propagation Modeling for Wireless Systems", EURASIP Journal on Wireless Communications and Networking. Hindawi Publishing Corp, 2009, p. 5.
Shimabukuko, F.I. et al., "Attenuation measurement of very low-loss dielectric waveguides by the cavity resonator method in the millimeter/submillimeter wavelength range." No. TR-0086A (2925-06)-1. Aerospace Corp El Segundo CA Electronics Research Lab, 1989.
Shindo, Shuichi et al., "Attenuation measurement of cylindrical dielectric-rod waveguide." Electronics Letters 12.5 (1976): 117-118.
Shumate, Paul W. et al., "Evolution of fiber in the residential loop plant." IEEE Communications Magazine 29.3 (1991): 68-74.
Sievenpiper, D.F. et al., "Two-dimensional beam steering using an electrically tunable impedance surface," in Antennas and Propagation, IEEE Transactions on , vol. 51, No. 10, pp. 2713-2722, Oct. 2003.
Strahler, Olivier , "Network Based VPNs", SANS Institute InfoSec Reading Room, sans.org, Aug. 2002.
Strieby, M.E. et al., "Television transmission over wire lines." American Institute of Electrical Engineers, Transactions of the 60.12 (1941): 1090-1096.
Szabó, Csaba A. , "European Broadband Initiatives with Public Participation", Broadband Services (2005): 255.
Taboada, John M. et al., "Thermo-optically tuned cascaded polymer waveguide taps." Applied physics letters 75.2 (1999): 163-165.
Templeton, Steven J. et al., "Detecting Spoofed Packets", DARPA Information Survivability Conference and Exposition, vol. 1, IEEE, 2003.
Theoleyr, Fabrice , "Internet of Things and M2M Communications", books.google.com, ISBN13: 9788792982483, Apr. 17, 2013.
Thornton, John et al., "Modern lens antennas for communications engineering", vol. 39, 2013.
Valladares, Cindy , "20 Critical Security Controls: Control 7—Wireless Device Control", Tripwire—The State of Security, tripwire.com, Mar. 21, 2013.
Vogelgesang, Ralf et al., "Plasmonic nanostructures in aperture-less scanning near-field optical microscopy (aSNOM)", physica status solidi (b) 245.10 (2008): 22552260.
Volat, C. et al., "De-icing/anti-icing techniques for power lines: current methods and future direction", Proceedings of the 11th International Workshop on Atmospheric Icing of Structures, Montreal, Canada. 2005.
Wagter, Herman , "Fiber-to-the-X: the economics of last-mile fiber", ARS Technica, arstechnica.com,, Mar. 31, 2010.
Wake, David et al., "Radio over fiber link design for next generation wireless systems", Lightwave Technology, Journal of28.16 (2010): 2456-2464.
Wang, Jing et al., "The influence of optical fiber bundle parameters on the transmission of laser speckle patterns", Optics express 22.8, 2014, 8908-8918.

(56) **References Cited**

OTHER PUBLICATIONS

Wilkins, George A. , "Fiber Optic Telemetry in Ocean Cable Systems", Chapter in new edition of Handbook of Oceanographic Winch, Wire and Cable Technology, Alan H. Driscoll, Ed.,(to be published by University of Rhode Island) (1986).

Wolff, Christian , "Phased Array Antenna" Radar Tutorial, web.archive.org, radartutorial.eu, Oct. 21, 2014.

Wu, Xidong et al., "Design and characterization of singleand multiplebeam mmwave circularly polarized substrate lens antennas for wireless communications", Microwave Theory and Techniques, IEEE Transactions on 49.3, 2001, 431-441.

Xi, Liu Xiao , "Security services in SoftLayer", Sep. 21, 2015.

Xia, Cen et al., "Supermodes for optical transmission", Optics express 19.17, 2011, 16653-16664.

Yeh, C. et al., "Ceramic Waveguides." Interplanetary Network Progress Report141.26 (2000): 1.

Yu, Shui et al., "Predicted packet padding for anonymous web browsing against traffic analysis attacks", Information Forensics and Security, IEEE Transactions on 7.4, http://nsp.org.au/syu/papers/tifs12.pdf, 2012, 1381-1393.

Zelby, Leon W. , "Propagation Modes on a Dielectric Coated Wire", J. The Franklin Institute, vol. 274(2), pp. 85-97, Aug. 1962.

Zheng, Zhu et al., "Efficient coupling of propagating broadband terahertz radial beams to metal wires", Optics express 21.9 (2013): 1064210650.

Zucker, "Surface-wave antennas", Antenna engineering handbook 4, 2007.

* cited by examiner

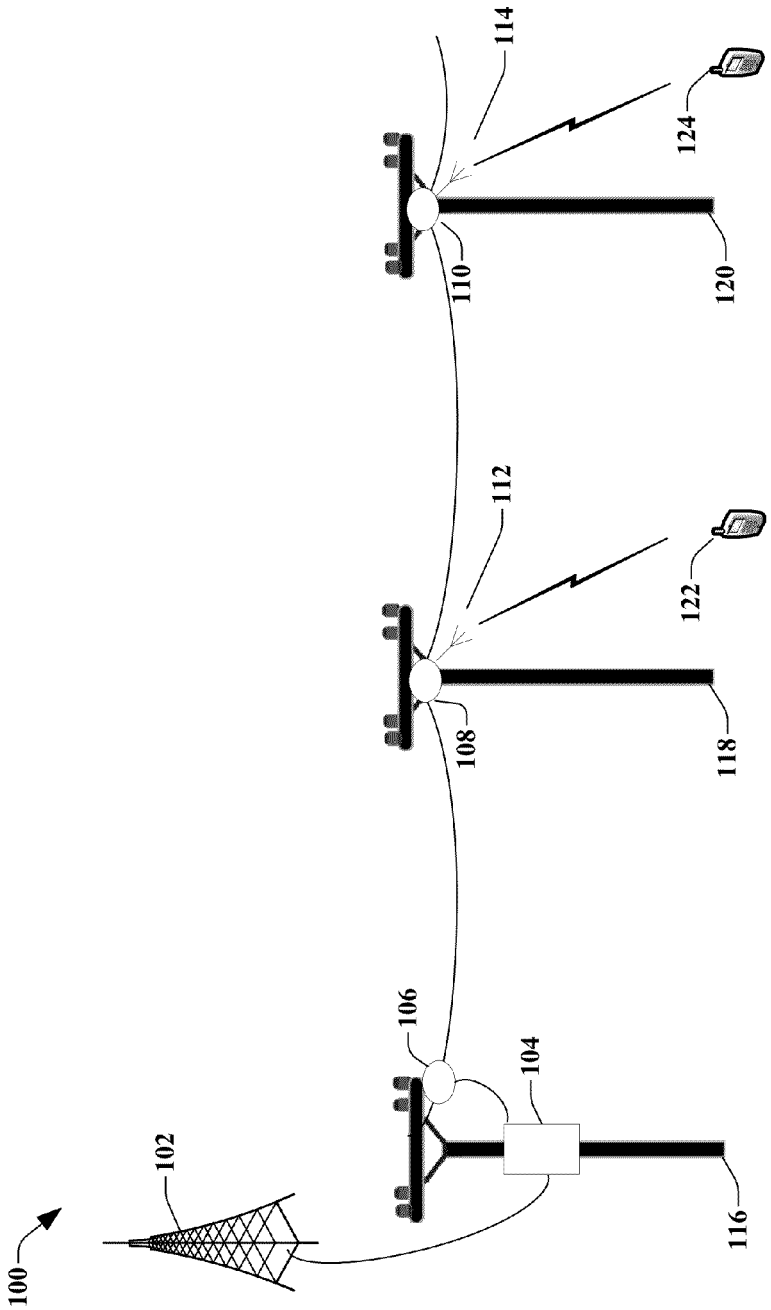


FIG. 1

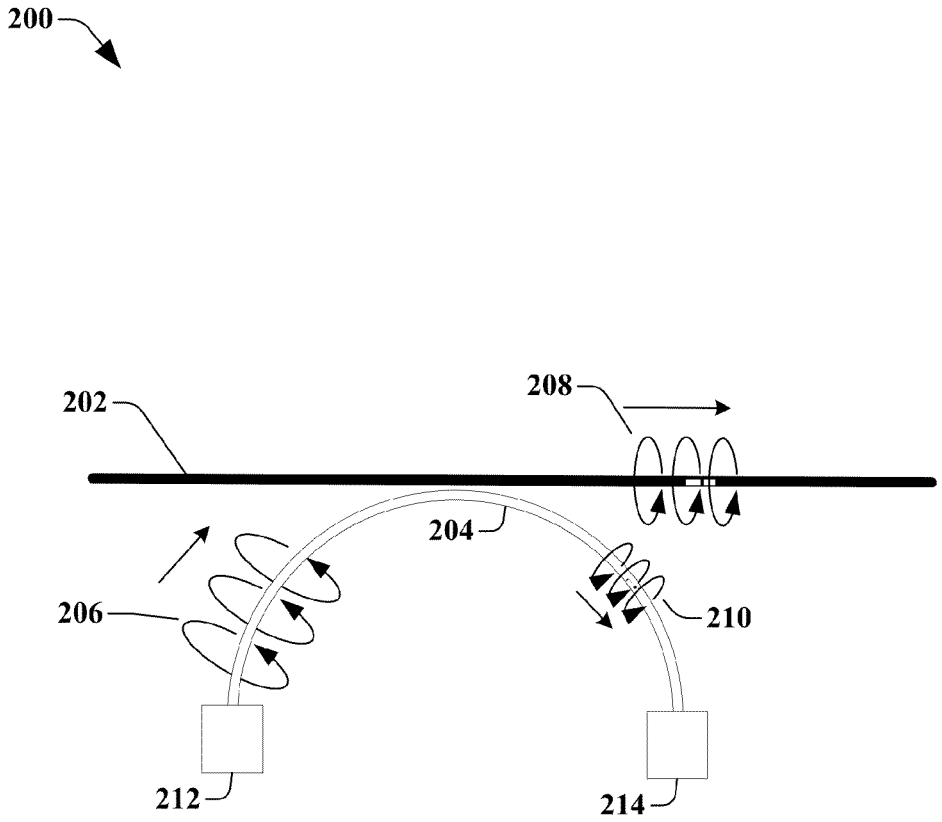


FIG. 2

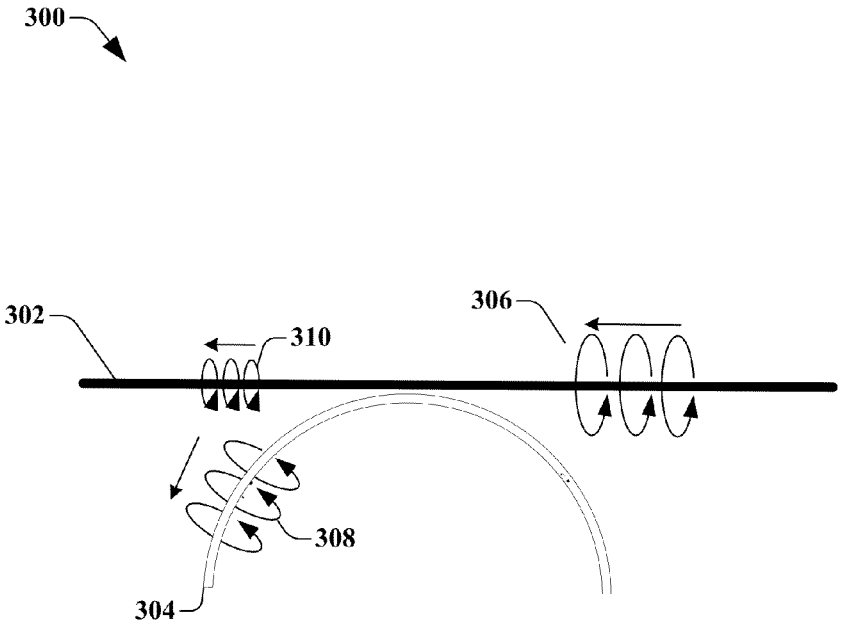


FIG. 3

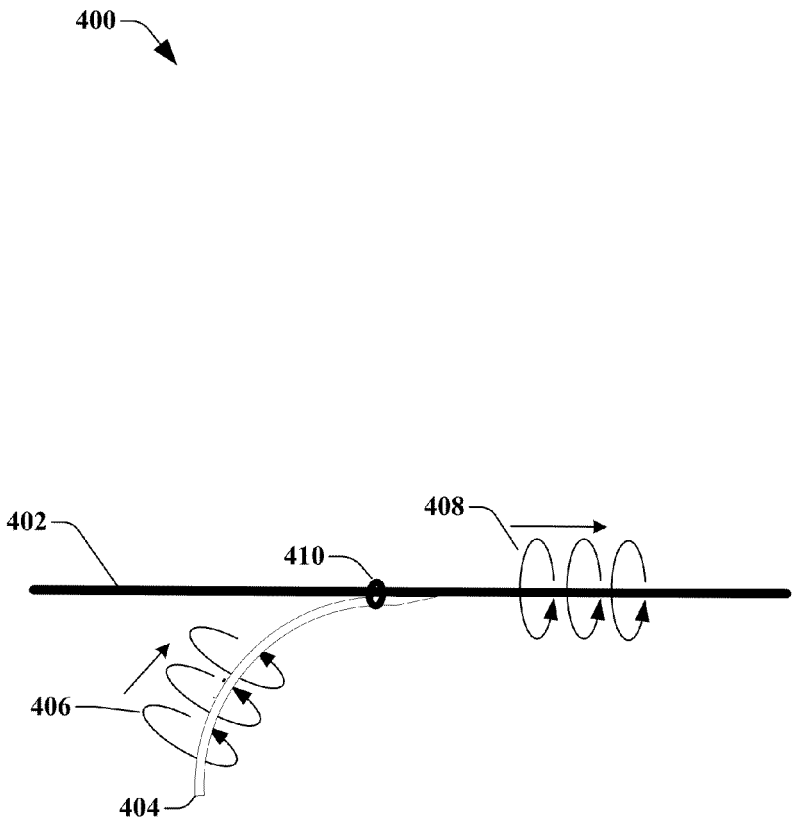


FIG. 4

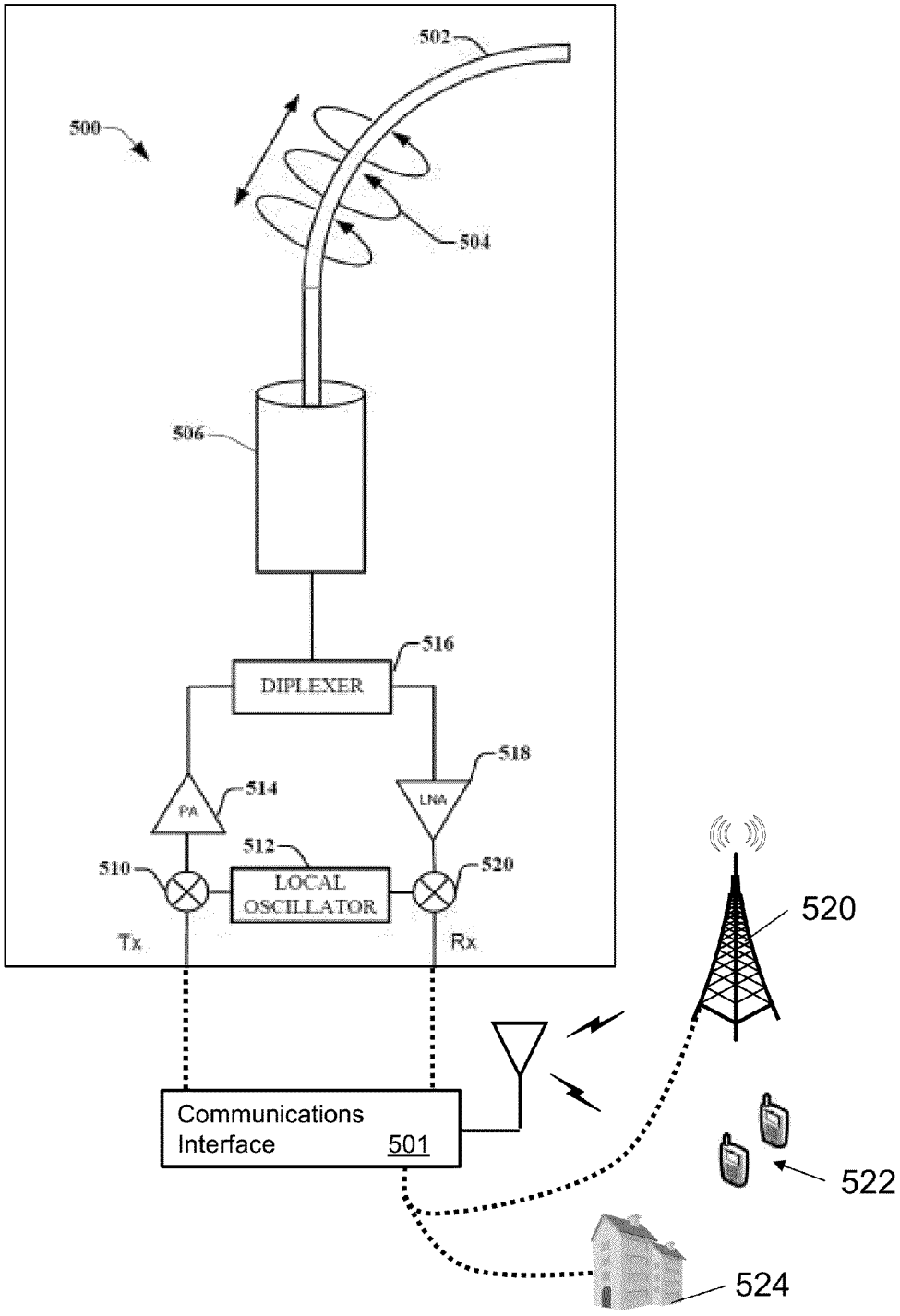

502
500
504
506
516
DIPLEXER
518
514
PA
LNA
512
510
LOCAL
OSCILLATOR
520
Tx
Rx
520
Communications
Interface 501
522
524

FIG. 5

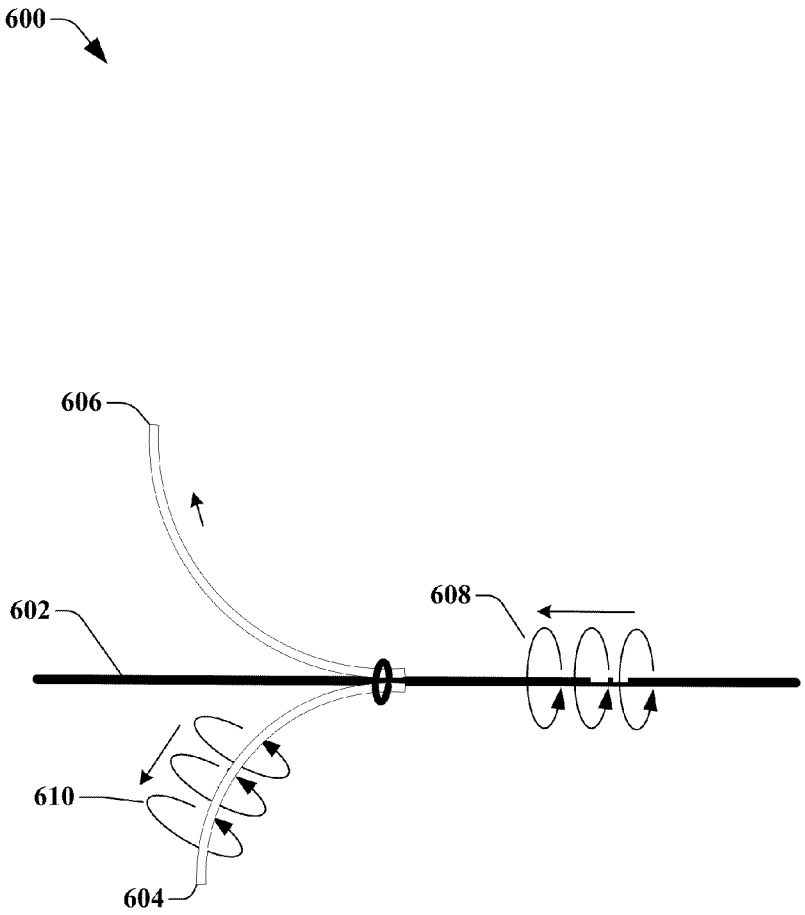


FIG. 6

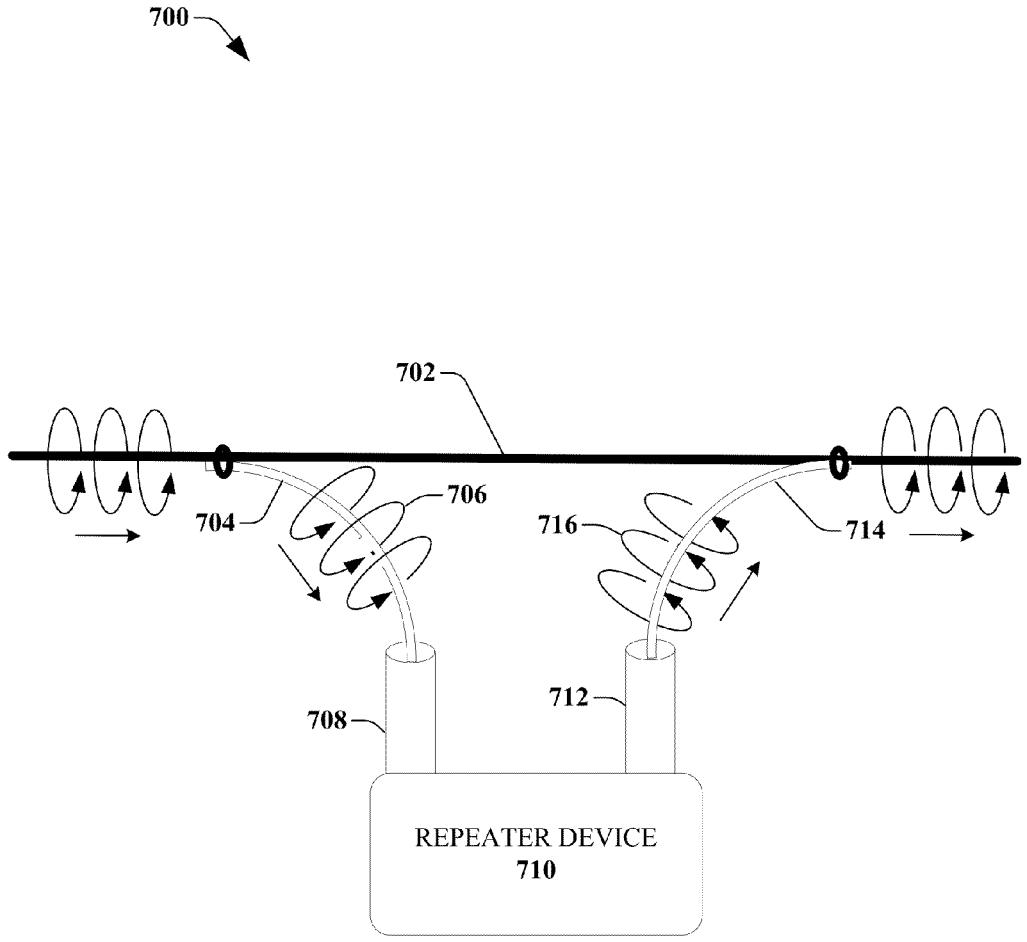


FIG. 7

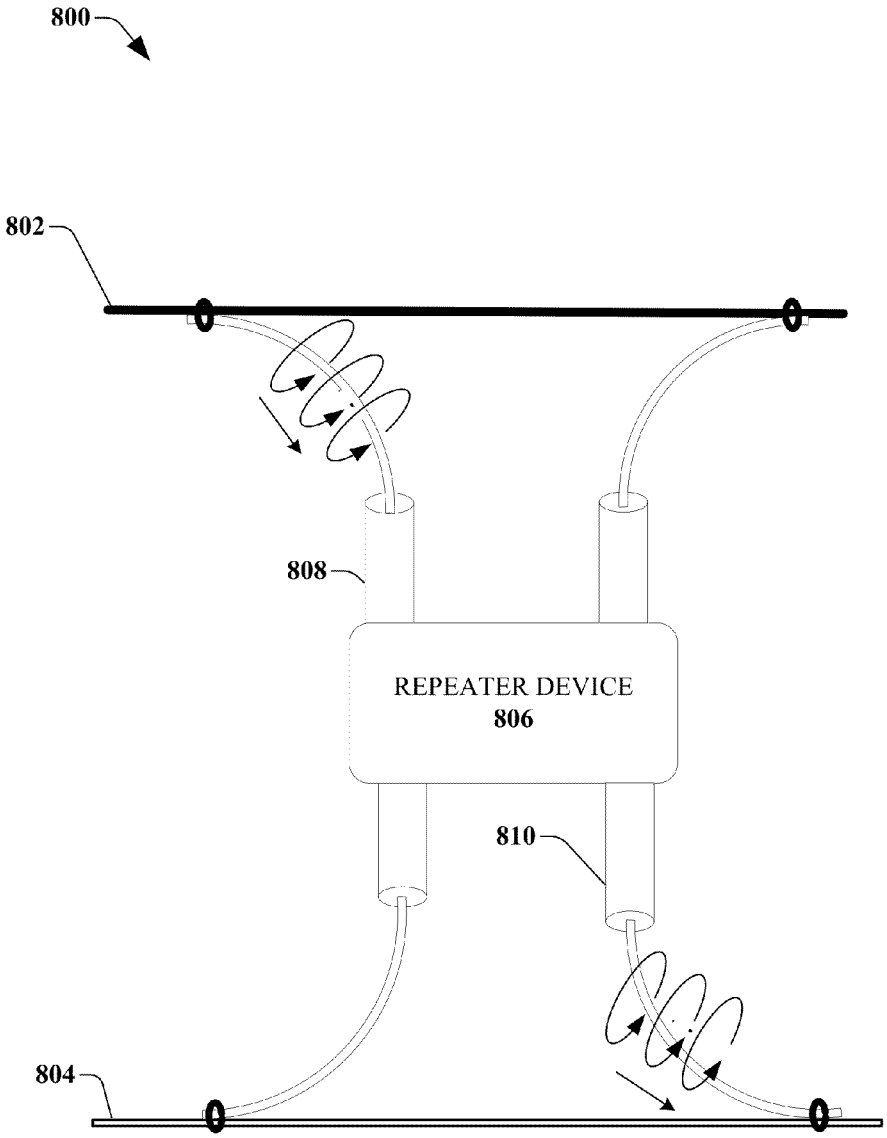


FIG. 8

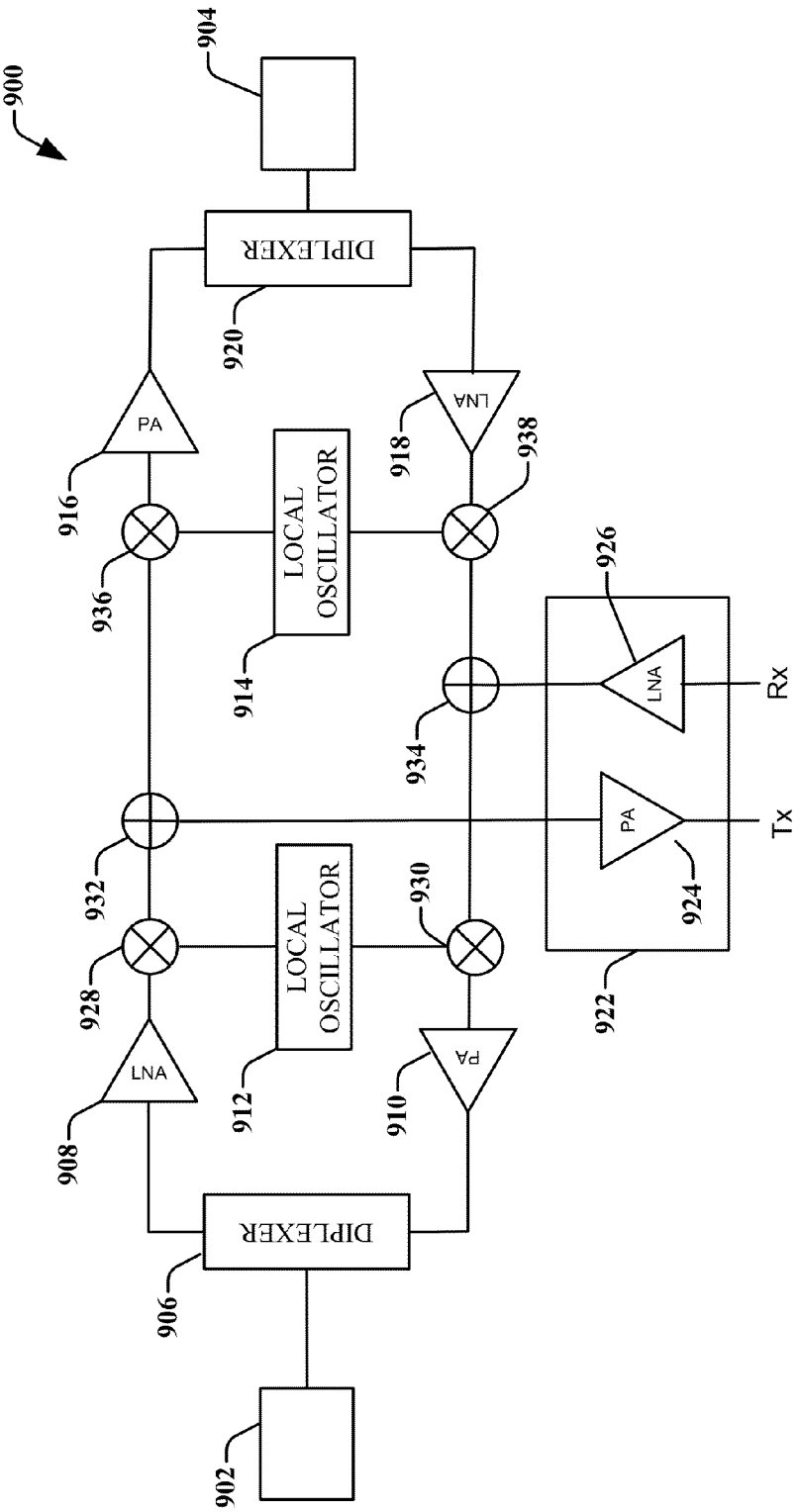

900
904
DIPLEXER
920
PA
LNA
916
918
938
936
LOCAL OSCILLATOR
914
926
LNA
Rx
934
PA
Tx
932
924
930
LOCAL OSCILLATOR
928
922
LNA
PA
912
910
908
DIPLEXER
906
902

FIG. 9

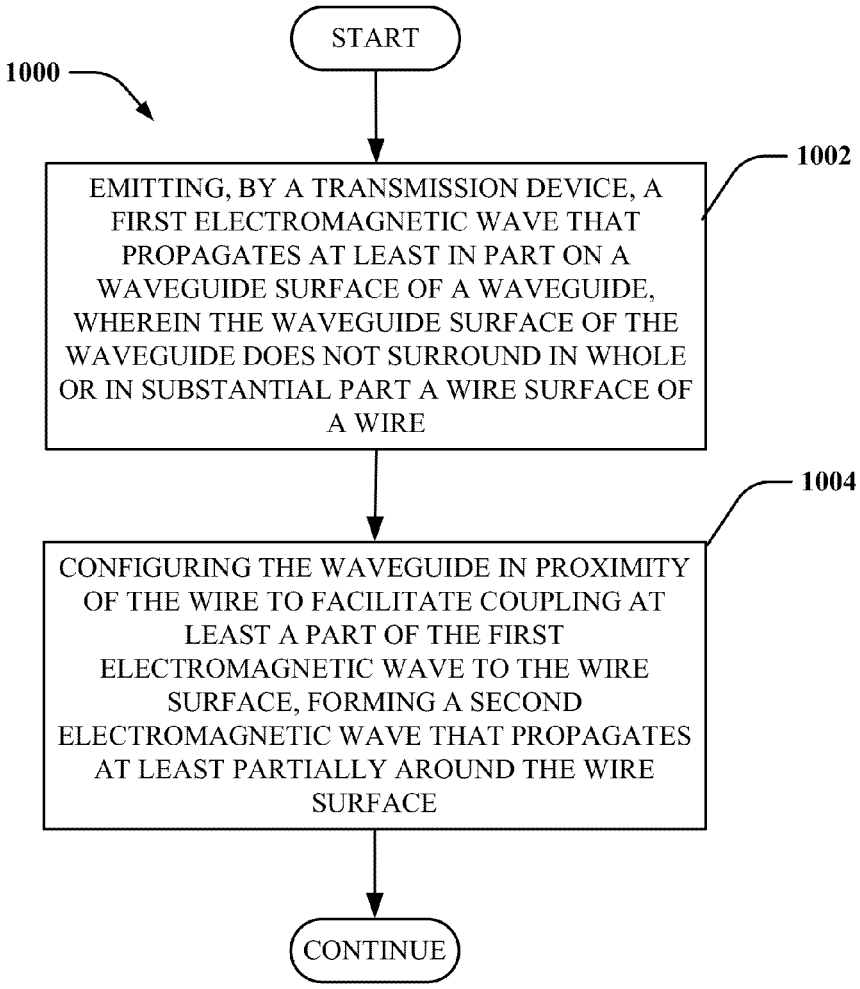

START
1000
1002
EMITTING, BY A TRANSMISSION DEVICE, A FIRST ELECTROMAGNETIC WAVE THAT PROPAGATES AT LEAST IN PART ON A WAVEGUIDE SURFACE OF A WAVEGUIDE, WHEREIN THE WAVEGUIDE SURFACE OF THE WAVEGUIDE DOES NOT SURROUND IN WHOLE OR IN SUBSTANTIAL PART A WIRE SURFACE OF A WIRE
1004
CONFIGURING THE WAVEGUIDE IN PROXIMITY OF THE WIRE TO FACILITATE COUPLING AT LEAST A PART OF THE FIRST ELECTROMAGNETIC WAVE TO THE WIRE SURFACE, FORMING A SECOND ELECTROMAGNETIC WAVE THAT PROPAGATES AT LEAST PARTIALLY AROUND THE WIRE SURFACE
CONTINUE

FIG. 10

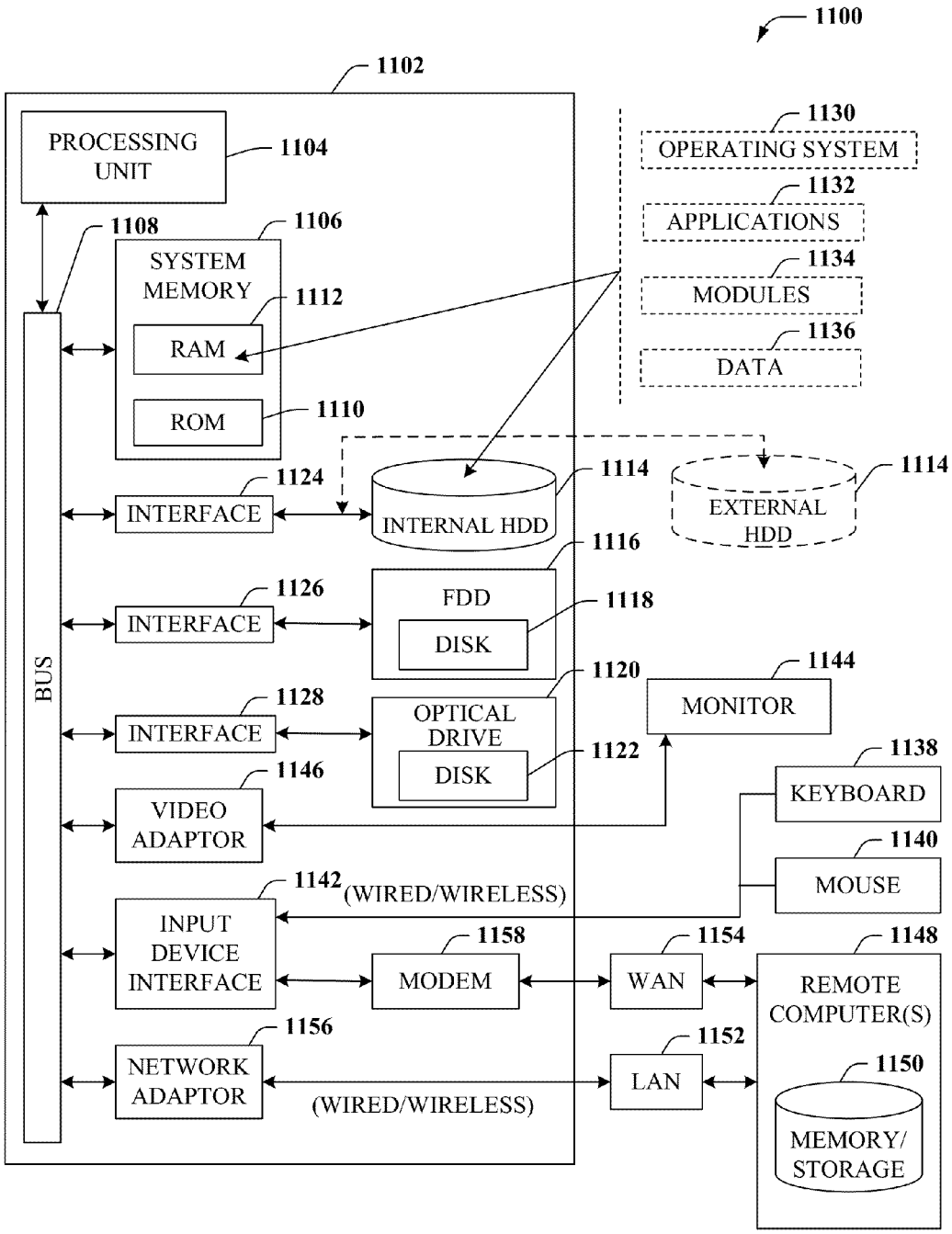

1100
1102
PROCESSING UNIT
1104
1108
1106
SYSTEM MEMORY
1112
RAM
ROM
1110
BUS
1130
OPERATING SYSTEM
1132
APPLICATIONS
1134
MODULES
1136
DATA
1124
INTERFACE
INTERNAL HDD
1114
EXTERNAL HDD
1114
1116
1126
INTERFACE
FDD
1118
DISK
1120
1128
INTERFACE
OPTICAL DRIVE
1122
DISK
1144
MONITOR
1146
VIDEO ADAPTOR
1138
KEYBOARD
1140
MOUSE
1142
(WIRED/WIRELESS)
INPUT DEVICE INTERFACE
1158
MODEM
1154
WAN
1148
REMOTE COMPUTER(S)
1156
NETWORK ADAPTOR
1152
LAN
1150
(WIRED/WIRELESS)
MEMORY/ STORAGE

FIG. 11

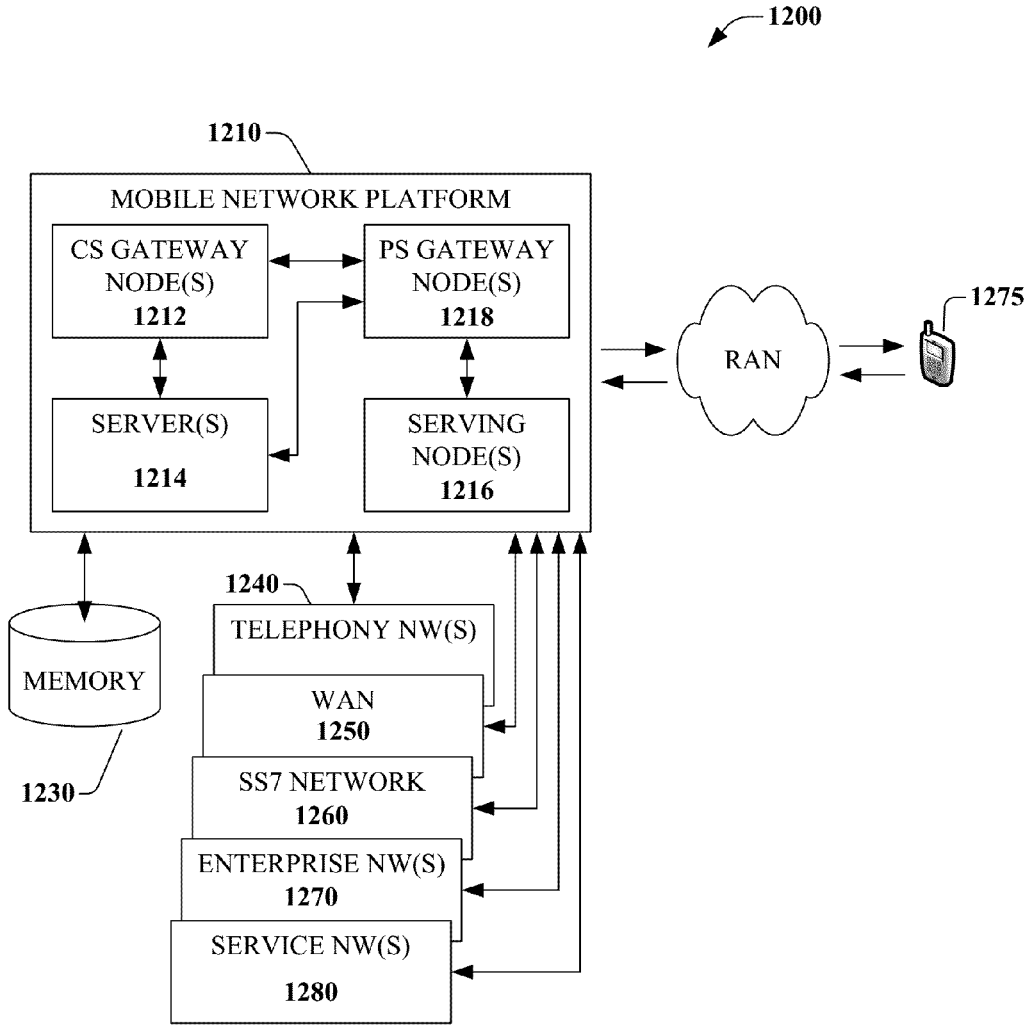

1200
1210
MOBILE NETWORK PLATFORM
CS GATEWAY NODE(S) 1212
PS GATEWAY NODE(S) 1218
SERVER(S) 1214
SERVING NODE(S) 1216
RAN
1275
MEMORY
1230
1240
TELEPHONY NW(S)
WAN 1250
SS7 NETWORK 1260
ENTERPRISE NW(S) 1270
SERVICE NW(S) 1280

FIG. 12

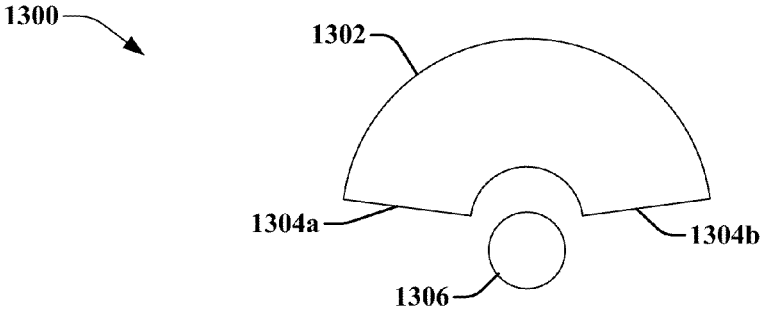


FIG. 13a

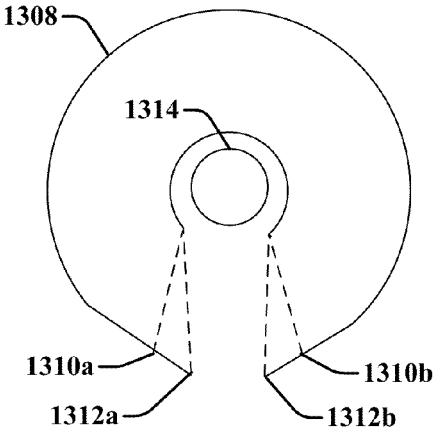


FIG. 13b

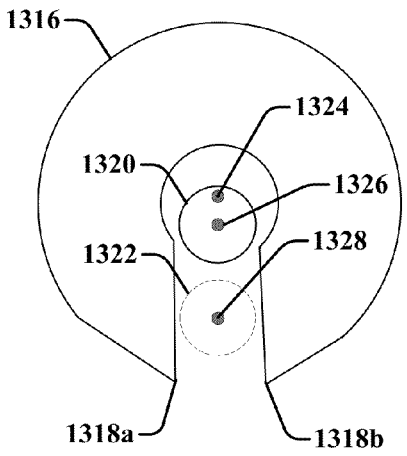


FIG. 13c

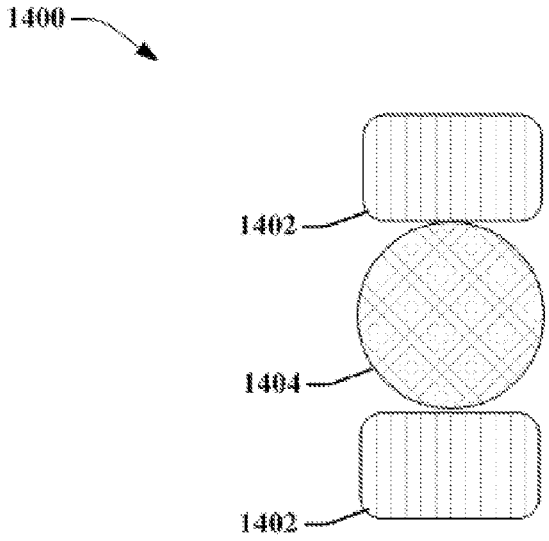


FIG. 14a

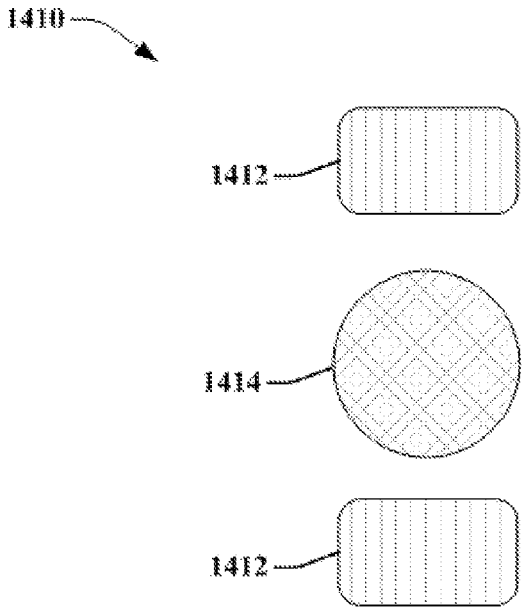


FIG. 14b

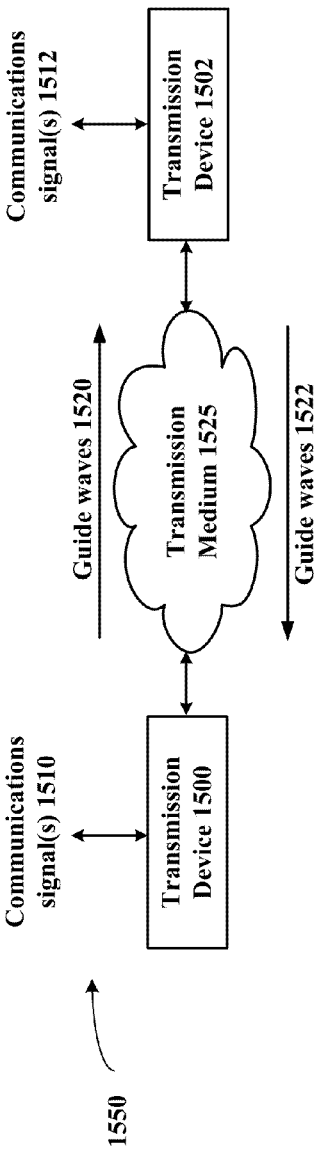


FIG. 15

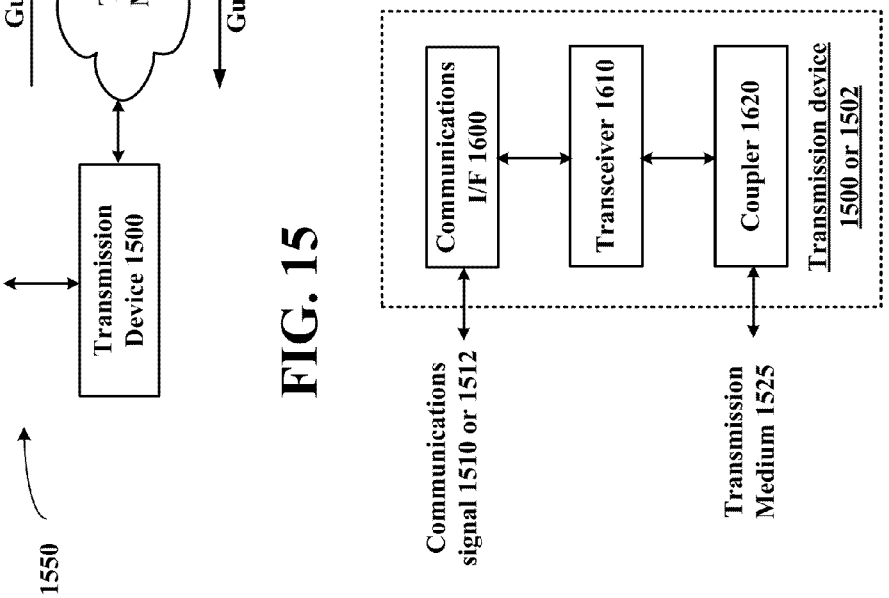


FIG. 16

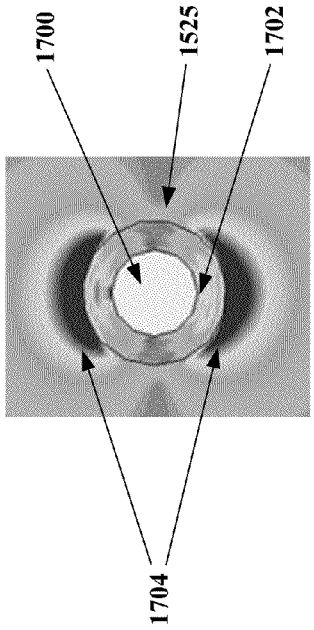


FIG. 17

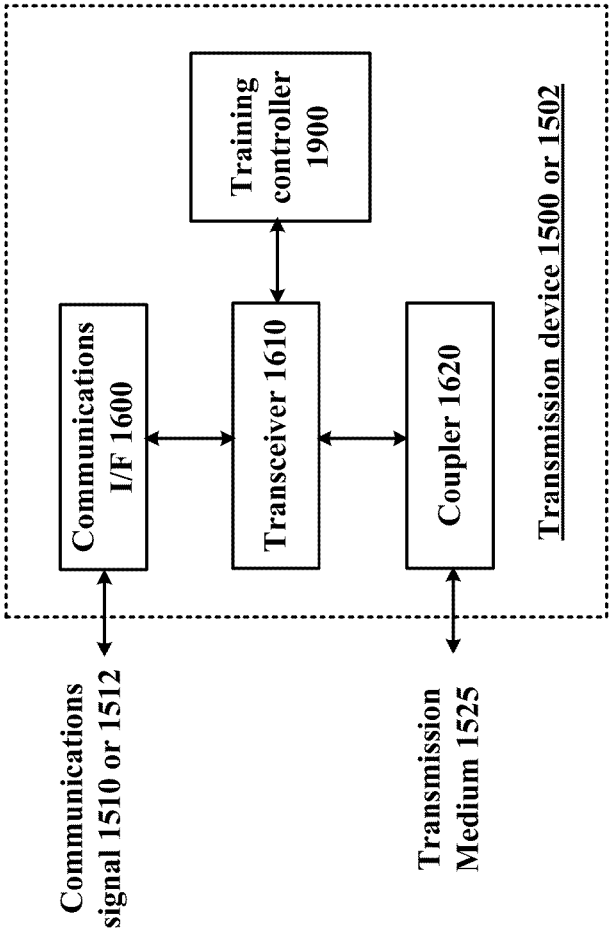

Training controller 1900
Communications I/F 1600
Transceiver 1610
Coupler 1620
Transmission device 1500 or 1502
Communications signal 1510 or 1512
Transmission Medium 1525

FIG. 19

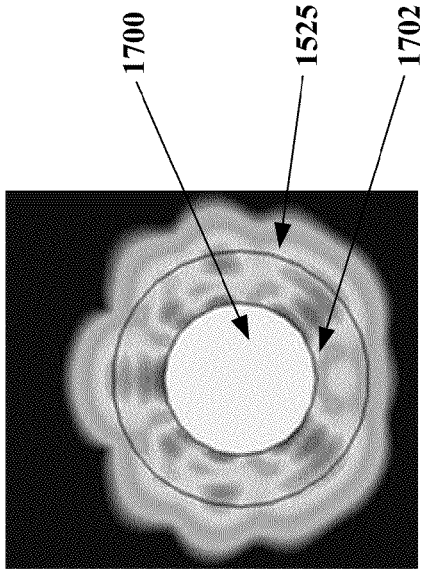

1700
1525
1702

FIG. 18

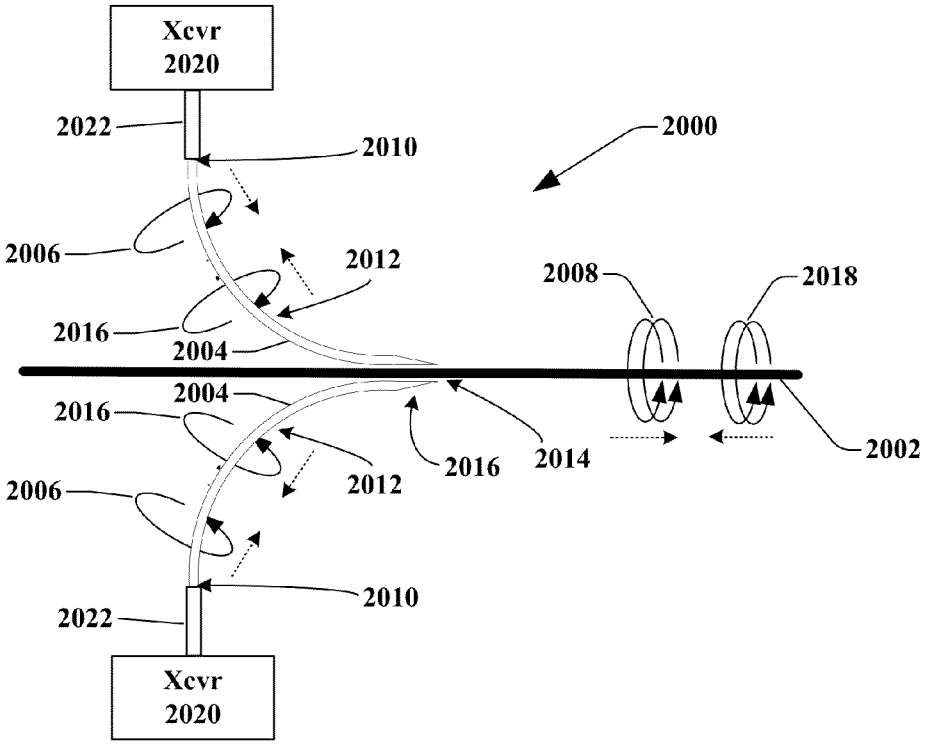

Xcvr
2020
2022
2010
2000
2006
2012
2008
2018
2016
2004
2004
2016
2014
2002
2016
2012
2006
2010
2022
Xcvr
2020

FIG. 20

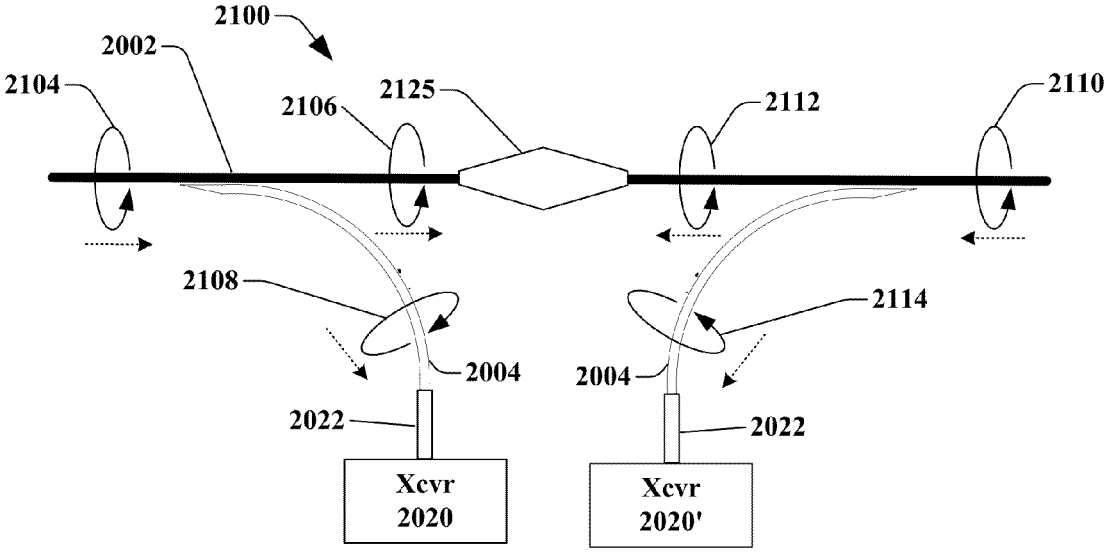

2100
2002
2104
2106
2125
2112
2110
2108
2114
2004
2004
2022
2022
Xcvr
2020
Xcvr
2020'

FIG. 21

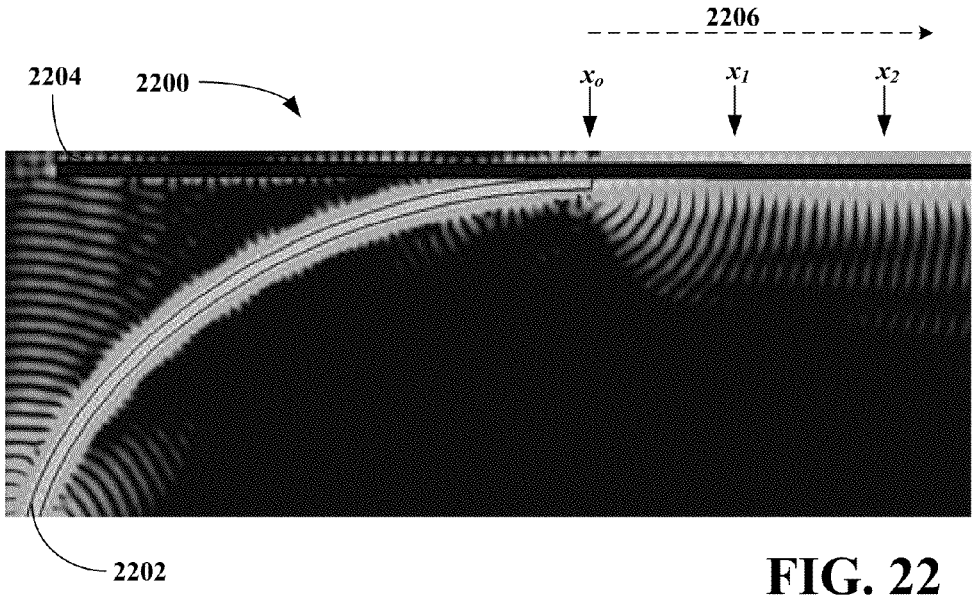

2206
2204
2200
x_o
x_1
x_2
2202

FIG. 22

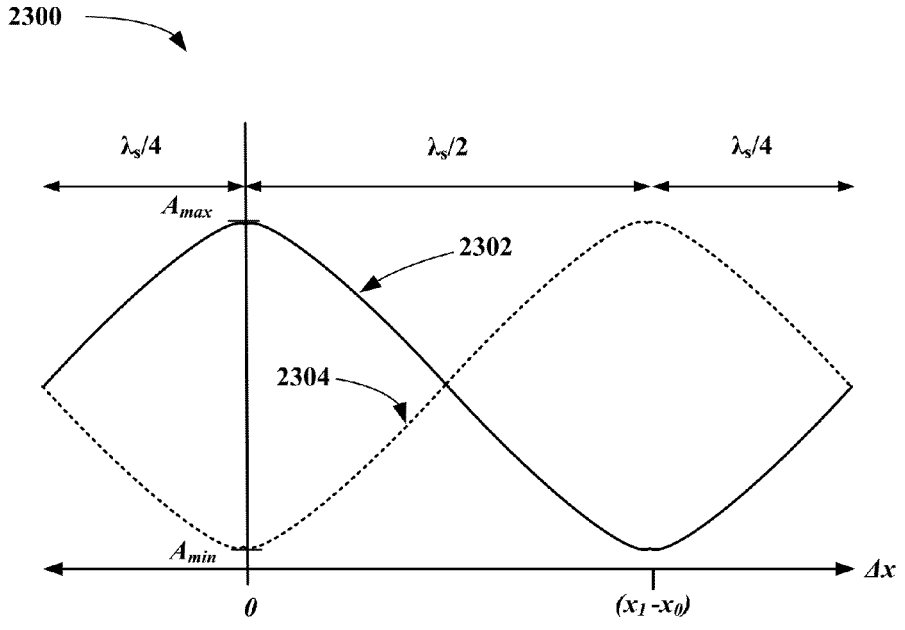

2300
$\lambda_s/4$
$\lambda_s/2$
$\lambda_s/4$
A_{max}
2302
2304
A_{min}
Δx
0
$(x_1 - x_0)$

FIG. 23

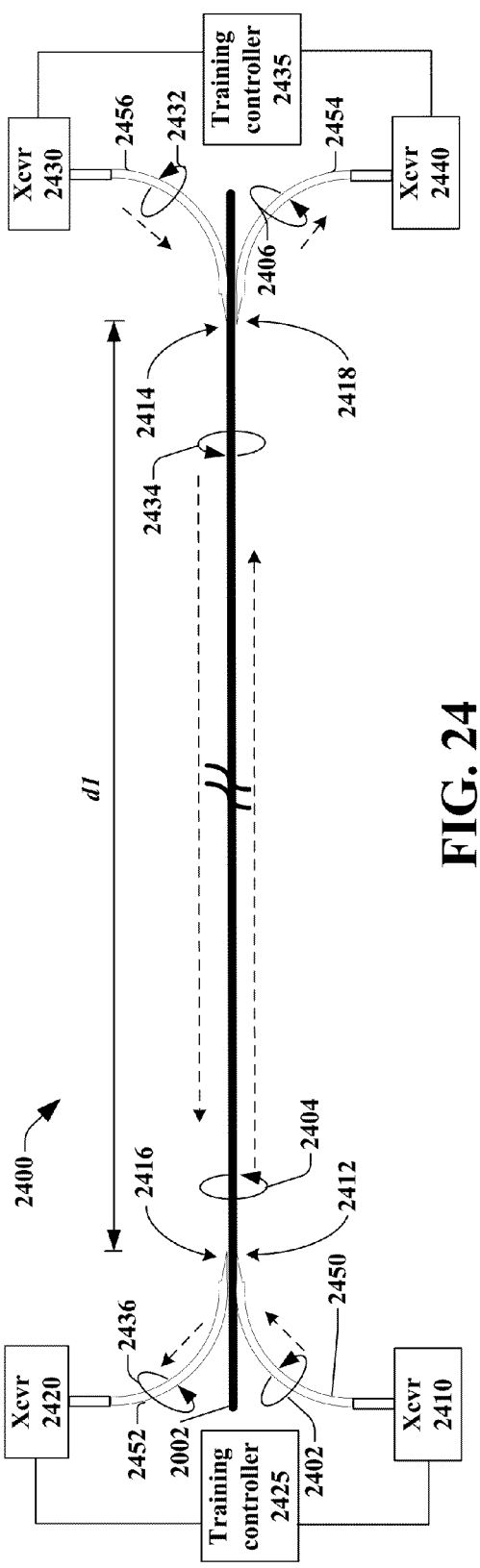

Xcvr 2430
Training controller 2435
Xcvr 2440
2456
2432
2454
2406
2414
2418
2434
d1
2400
2416
2404
2412
2450
2436
Xcvr 2420
Xcvr 2410
2452
2002
Training controller 2425
2402

FIG. 24

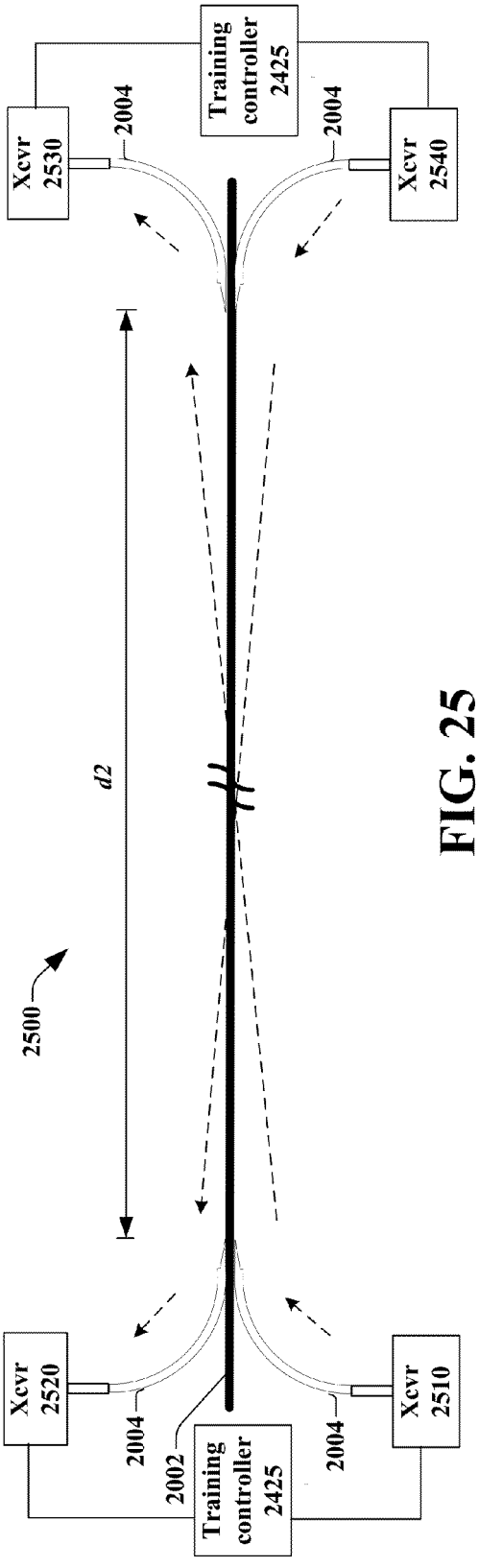

Xcvr 2530
Training controller 2425
Xcvr 2540
2004
2004
d2
2500
Xcvr 2520
Xcvr 2510
2004
2004
2002
Training controller 2425

FIG. 25

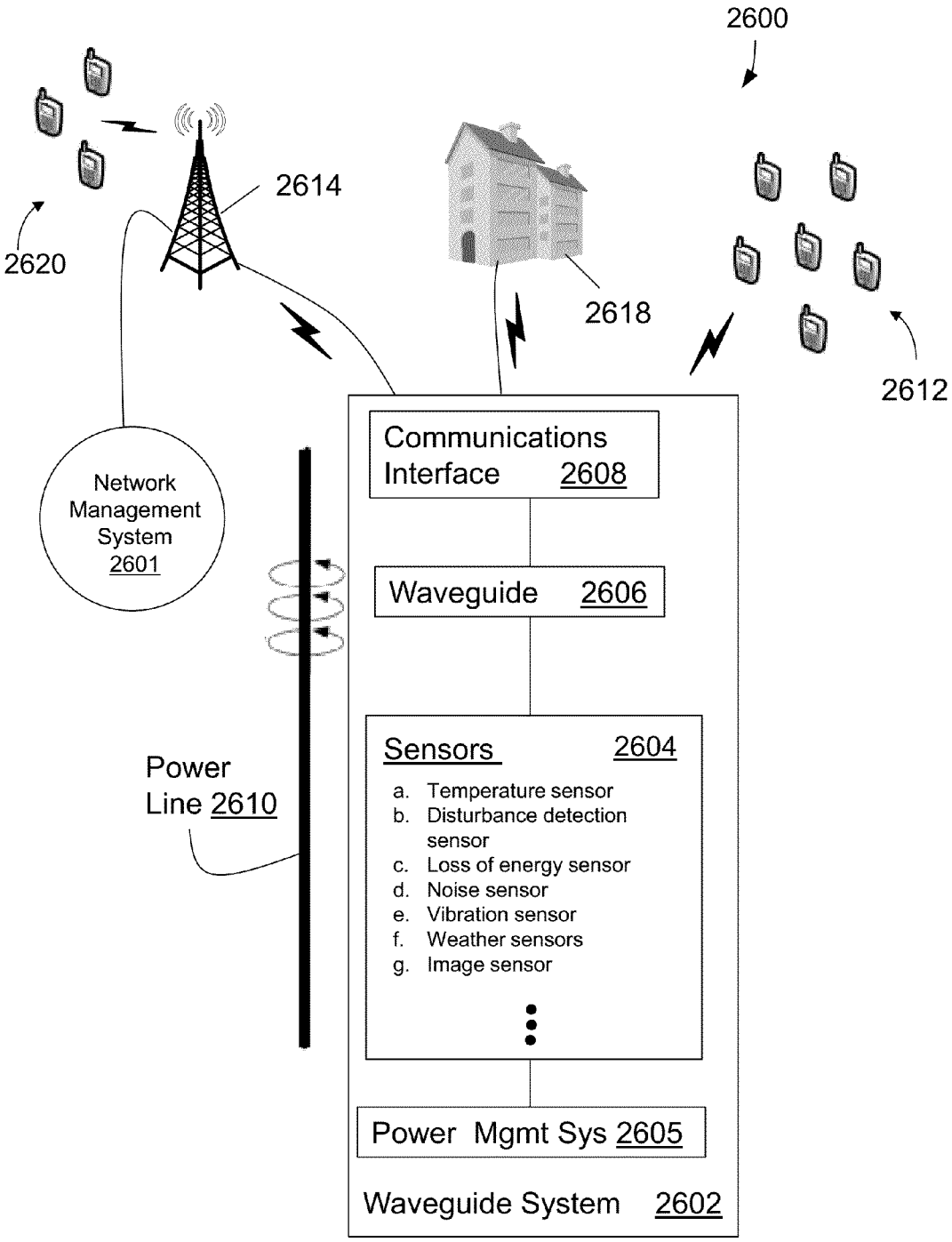

2600
2614
2620
2618
2612
Communications Interface 2608
Network Management System 2601
Waveguide 2606
Sensors 2604
a. Temperature sensor
b. Disturbance detection sensor
c. Loss of energy sensor
d. Noise sensor
e. Vibration sensor
f. Weather sensors
g. Image sensor
Power Line 2610
Power Mgmt Sys 2605
Waveguide System 2602

FIG. 26

FIG. 27(A)

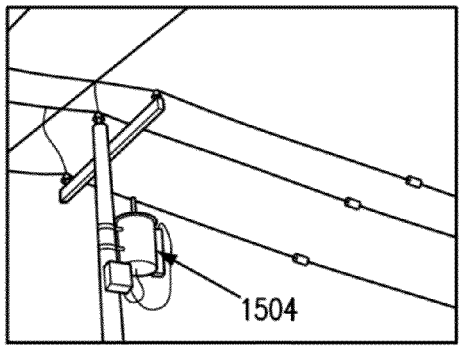


FIG. 27(B)

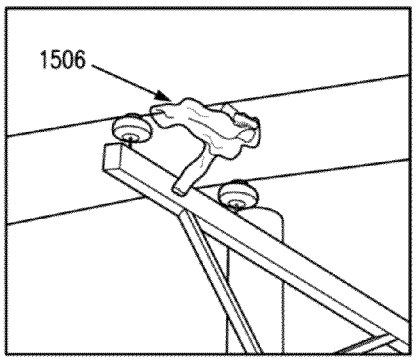


FIG. 27(C)

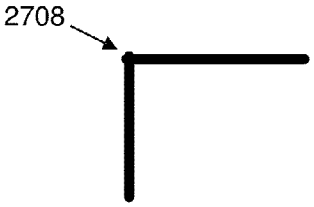


FIG. 27(D)

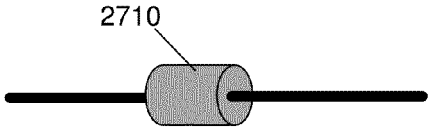


FIG. 27(E)

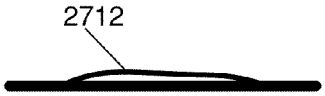


FIG. 27(F)

FIG. 27(G)

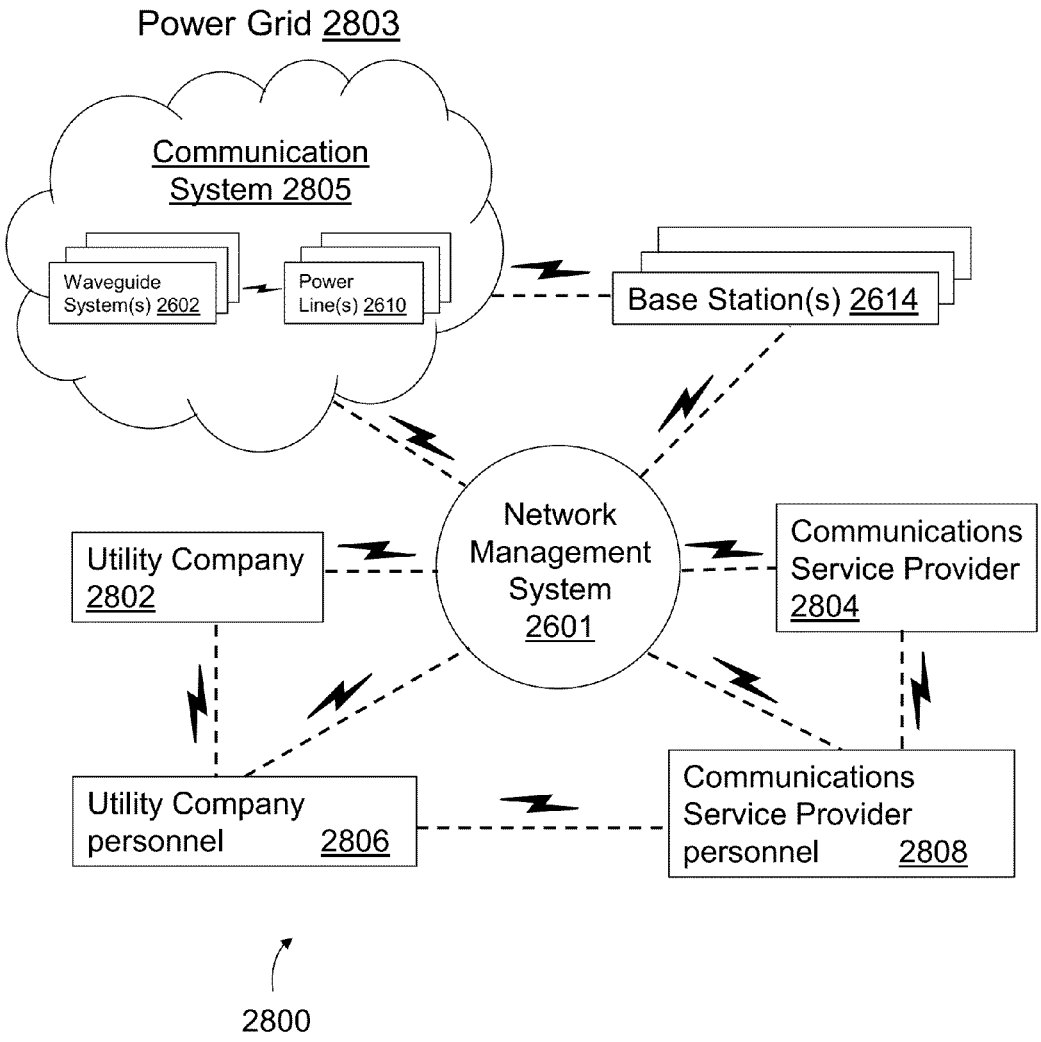

Power Grid 2803
Communication System 2805
Waveguide System(s) 2602
Power Line(s) 2610
Base Station(s) 2614
Network Management System 2601
Utility Company 2802
Communications Service Provider 2804
Utility Company personnel 2806
Communications Service Provider personnel 2808
2800

FIG. 28

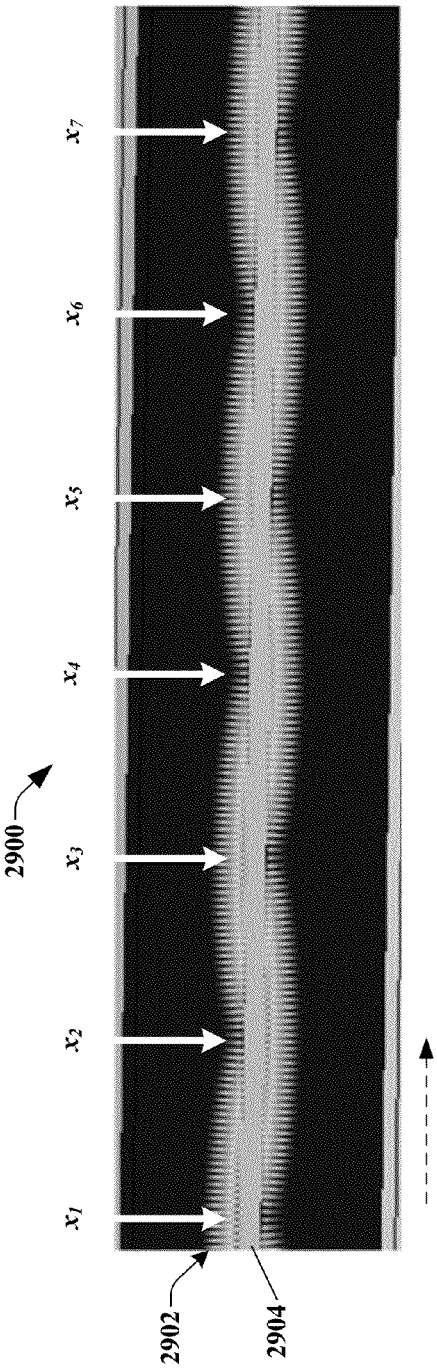


FIG. 29

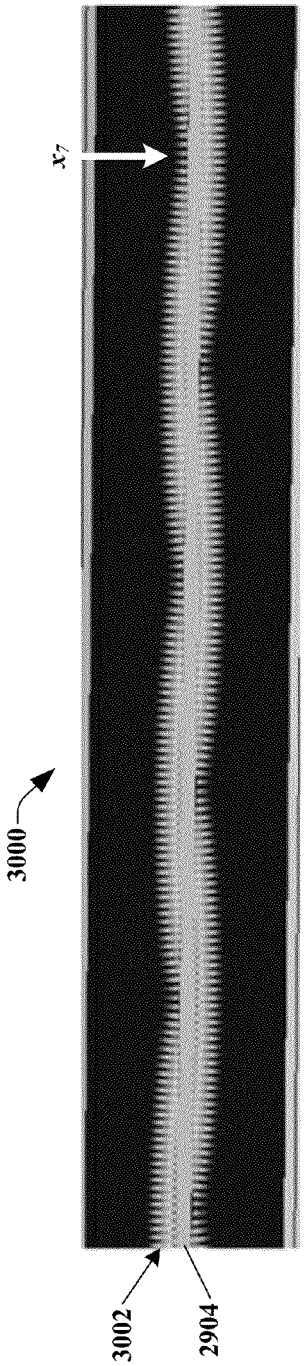


FIG. 30

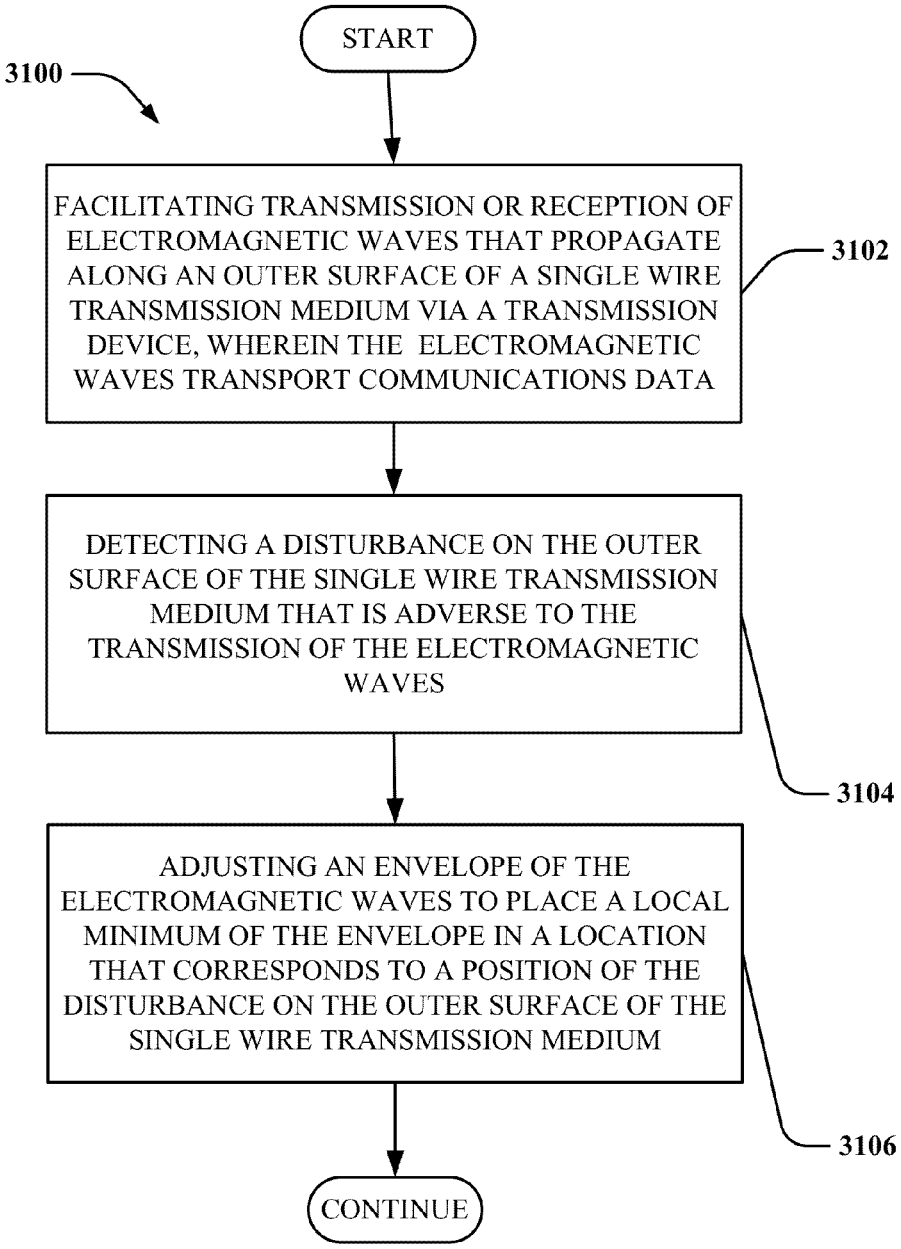

START
3100
FACILITATING TRANSMISSION OR RECEPTION OF ELECTROMAGNETIC WAVES THAT PROPAGATE ALONG AN OUTER SURFACE OF A SINGLE WIRE TRANSMISSION MEDIUM VIA A TRANSMISSION DEVICE, WHEREIN THE ELECTROMAGNETIC WAVES TRANSPORT COMMUNICATIONS DATA
3102
DETECTING A DISTURBANCE ON THE OUTER SURFACE OF THE SINGLE WIRE TRANSMISSION MEDIUM THAT IS ADVERSE TO THE TRANSMISSION OF THE ELECTROMAGNETIC WAVES
3104
ADJUSTING AN ENVELOPE OF THE ELECTROMAGNETIC WAVES TO PLACE A LOCAL MINIMUM OF THE ENVELOPE IN A LOCATION THAT CORRESPONDS TO A POSITION OF THE DISTURBANCE ON THE OUTER SURFACE OF THE SINGLE WIRE TRANSMISSION MEDIUM
3106
CONTINUE

FIG. 31

TRANSMISSION DEVICE WITH IMPAIRMENT COMPENSATION AND METHODS FOR USE THEREWITH

FIELD OF THE DISCLOSURE

The subject disclosure relates to communications via microwave transmission in a communication network.

BACKGROUND

As smart phones and other portable devices increasingly become ubiquitous, and data usage increases, macrocell base station devices and existing wireless infrastructure in turn require higher bandwidth capability in order to address the increased demand. To provide additional mobile bandwidth, small cell deployment is being pursued, with microcells and picocells providing coverage for much smaller areas than traditional macrocells.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram illustrating an example, non-limiting embodiment of a guided wave communications system in accordance with various aspects described herein.

FIG. **2** is a block diagram illustrating an example, non-limiting embodiment of a dielectric waveguide coupler in accordance with various aspects described herein.

FIG. **3** is a block diagram illustrating an example, non-limiting embodiment of a dielectric waveguide coupler in accordance with various aspects described herein.

FIG. **4** is a block diagram illustrating an example, non-limiting embodiment of a dielectric waveguide coupler in accordance with various aspects described herein.

FIG. **5** is a block diagram illustrating an example, non-limiting embodiment of a dielectric waveguide coupler and transceiver in accordance with various aspects described herein.

FIG. **6** is a block diagram illustrating an example, non-limiting embodiment of a dual dielectric waveguide coupler in accordance with various aspects described herein.

FIG. **7** is a block diagram illustrating an example, non-limiting embodiment of a bidirectional dielectric waveguide coupler in accordance with various aspects described herein.

FIG. **8** illustrates a block diagram illustrating an example, non-limiting embodiment of a bidirectional dielectric waveguide coupler in accordance with various aspects described herein.

FIG. **9** illustrates a block diagram illustrating an example, non-limiting embodiment of a bidirectional repeater system in accordance with various aspects described herein.

FIG. **10** illustrates a flow diagram of an example, non-limiting embodiment of a method for transmitting a transmission with a dielectric waveguide coupler as described herein.

FIG. **11** is a block diagram of an example, non-limiting embodiment of a computing environment in accordance with various aspects described herein.

FIG. **12** is a block diagram of an example, non-limiting embodiment of a mobile network platform in accordance with various aspects described herein.

FIGS. **13***a*, **13***b*, and **13***c* are block diagrams illustrating example, non-limiting embodiments of a slotted waveguide coupler in accordance with various aspects described herein.

FIGS. **14***a* and **14***b* are a block diagrams illustrating an example, non-limiting embodiment of a waveguide coupling system in accordance with various aspects described herein.

FIG. **15** is a block diagram illustrating an example, non-limiting embodiment of a guided wave communication system in accordance with various aspects described herein.

FIG. **16** is a block diagram illustrating an example, non-limiting embodiment of a transmission device in accordance with various aspects described herein.

FIG. **17** is a diagram illustrating an example, non-limiting embodiment of an electromagnetic distribution in accordance with various aspects described herein.

FIG. **18** is a diagram illustrating an example, non-limiting embodiment of an electromagnetic distribution in accordance with various aspects described herein.

FIG. **19** is a block diagram illustrating an example, non-limiting embodiment of a transmission device in accordance with various aspects described herein.

FIG. **20** is a block diagram of an example, non-limiting embodiment of a transmission device in accordance with various aspects described herein.

FIG. **21** is a block diagram of an example, non-limiting embodiment of a transmission device in accordance with various aspects described herein.

FIG. **22** is a diagram illustrating an example, non-limiting embodiment of an electromagnetic distribution in accordance with various aspects described herein.

FIG. **23** is a diagram illustrating an example, non-limiting embodiment of a functions in accordance with various aspects described herein.

FIG. **24** is a block diagram of an example, non-limiting embodiment of a transmission system in accordance with various aspects described herein.

FIG. **25** is a block diagram of an example, non-limiting embodiment of a transmission system in accordance with various aspects described herein.

FIG. **26** is a block diagram illustrating an example, non-limiting embodiment of a waveguide system in accordance with various aspects described herein.

FIGS. **27**A, **27**B, **27**C, **27**D, **27**E, **27**F and **27**G illustrate example, non-limiting embodiments of sources for impairments detectable by the waveguide system of FIG. **26** as described herein.

FIG. **28** is a block diagram illustrating an example, non-limiting embodiment of a system for managing a power grid communication system in accordance with various aspects described herein.

FIG. **29** is a diagram illustrating an example, non-limiting embodiment of an electromagnetic distribution in accordance with various aspects described herein.

FIG. **30** is a diagram illustrating an example, non-limiting embodiment of an electromagnetic distribution in accordance with various aspects described herein.

FIG. **31** illustrates a flow diagram of an example, non-limiting embodiment of a method of transmission as described herein.

DETAILED DESCRIPTION

One or more embodiments are now described with reference to the drawings, wherein like reference numerals are used to refer to like elements throughout. In the following description, for purposes of explanation, numerous details are set forth in order to provide a thorough understanding of the various embodiments. It is evident, however, that the various embodiments can be practiced in different combinations and without these details (and without applying to any particular networked environment or standard).

To provide network connectivity to additional base station devices, the backhaul network that links the communication

cells (e.g., microcells and macrocells) to network devices of the core network correspondingly expands. Similarly, to provide network connectivity to a distributed antenna system, an extended communication system that links base station devices and their distributed antennas is desirable. A guided wave communication system can be provided to enable alternative, increased or additional network connectivity and a waveguide coupling system can be provided to transmit and/or receive guided wave (e.g., surface wave) communications on a transmission medium, such as a wire or other conductor that operates as a single-wire transmission line or a dielectric material that operates as a waveguide and/or another transmission medium that otherwise operates to guide the transmission of an electromagnetic wave.

In an example embodiment, a waveguide coupler that is utilized in a waveguide coupling system can be made of a dielectric material, or other low-loss insulator (e.g., Teflon, polyethylene, etc.), or can be made of a conducting (e.g., metallic, non-metallic, etc.) material, or any combination of the foregoing materials. Reference throughout the detailed description to "dielectric waveguide" is for illustration purposes and does not limit embodiments to being constructed solely of dielectric materials. In other embodiments, other dielectric or insulating materials are possible. It will be appreciated that a variety of transmission media such as: wires, whether insulated or not, and whether single-stranded or multi-stranded; conductors of other shapes or configurations including wire bundles, cables, rods, rails, pipes; non-conductors such as dielectric pipes, rods, rails, or other dielectric members; combinations of conductors and dielectric materials; or other guided wave transmission media can be utilized with guided wave communications without departing from example embodiments.

For these and/or other considerations, in one or more embodiments, a transmission device includes a communications interface that receives a first communication signal that includes first data. A transceiver generates a first electromagnetic wave based on the first communication signal to convey the first data, the first electromagnetic wave having at least one carrier frequency and at least one corresponding wavelength. A coupler couples the first electromagnetic wave to a transmission medium having at least one inner portion surrounded by a dielectric material, the dielectric material having an outer surface and a corresponding circumference, wherein the coupling of the first electromagnetic wave to the transmission medium forms a second electromagnetic wave that is guided to propagate along the outer surface of the dielectric material via at least one guided wave mode that includes an asymmetric mode, wherein the at least one carrier frequency is within a millimeter wave frequency band and wherein the at least one corresponding wavelength is less than the circumference of the transmission medium.

In one or more embodiments, a transmission device includes a transmitter that generates a first electromagnetic wave based on a communication signal to convey data, the first electromagnetic wave having at least one carrier frequency and at least one corresponding wavelength. A coupler couples the first electromagnetic wave to a single wire transmission medium having an outer surface and a corresponding circumference, wherein the coupling of the first electromagnetic wave to the single wire transmission medium forms a second electromagnetic wave that is guided to propagate along the outer surface of the single wire transmission medium via at least one guided wave mode that includes an asymmetric mode, wherein the at least one carrier frequency in within a millimeter wave frequency band and wherein the at least one corresponding wavelength is less than the circumference of the single wire transmission medium.

In one or more embodiments, a method includes generating a first electromagnetic wave based on a communication signal to convey data, the first electromagnetic wave having at least one carrier frequency and at least one corresponding wavelength. A coupler couples the first electromagnetic wave to a single wire transmission medium having an outer dielectric surface and a corresponding circumference, wherein the coupling of the first electromagnetic wave to the single wire transmission medium forms a second electromagnetic wave that is guided to propagate along the outer dielectric surface of the single wire transmission medium via at least one guided wave mode, wherein the at least one carrier frequency is within a millimeter wave frequency band and wherein the at least one corresponding wavelength is less than the circumference of the single wire transmission medium.

In one or more embodiments, a transmission device includes a communications interface that receives a first communication signal that includes first data. A transceiver generates a first electromagnetic wave based on the first communication signal to convey the first data, the first electromagnetic wave having at least one carrier frequency. A coupler couples the first electromagnetic wave to a transmission medium having at least one inner portion surrounded by a dielectric material, the dielectric material having an outer surface and a corresponding circumference, wherein the coupling of the first electromagnetic wave to the transmission medium forms a second electromagnetic wave that is guided to propagate along the outer surface of the dielectric material via at least one guided wave mode that includes an asymmetric mode having a lower cutoff frequency, and wherein the at least one carrier frequency is selected to be within a limited range of the lower cutoff frequency.

In one or more embodiments, a transmission device includes a transmitter that generates a first electromagnetic wave based on a communication signal to convey data, the first electromagnetic wave having at least one carrier frequency. A coupler, coupled to the transmitter, couples the first electromagnetic wave to a single wire transmission medium having an outer surface, wherein the coupling of the first electromagnetic wave to the single wire transmission medium forms a second electromagnetic wave that is guided to propagate along the outer surface of the single wire transmission medium via at least one guided wave mode that includes an asymmetric mode having a lower cutoff frequency, and wherein the at least one carrier frequency is selected to be within a limited range of the lower cutoff frequency.

In one or more embodiments, a method includes generating a first electromagnetic wave based on a communication signal to convey data, the first electromagnetic wave having at least one carrier frequency. A coupler couples the first electromagnetic wave to a single wire transmission medium having an outer surface, wherein the coupling of the first electromagnetic wave to the single wire transmission medium forms a second electromagnetic wave that is guided to propagate along the outer surface of the single wire transmission medium via at least one guided wave mode that includes an asymmetric mode having a lower cutoff frequency, and wherein the at least one carrier frequency is selected to be within a limited range of the lower cutoff frequency.

In one or more embodiments, a method includes generating a first electromagnetic wave based on a communication signal to convey data, the first electromagnetic wave having at least one carrier frequency. The first electromagnetic wave is coupled to a single wire transmission medium having an outer surface, wherein the coupling of the first electromagnetic

wave to the single wire transmission medium forms a second electromagnetic wave that is guided to propagate along the outer surface of the single wire transmission medium via at least one guided wave mode that includes an asymmetric mode having a lower cutoff frequency, and wherein the at least one carrier frequency is selected to be within a limited range of the lower cutoff frequency.

Various embodiments described herein relate to a transmission system for launching and extracting guided wave (e.g., surface wave communications that are electromagnetic waves) transmissions from a wire. At millimeter-wave frequencies, wherein the wavelength is small compared to the size of the equipment, transmissions can propagate as waves guided by a waveguide, such as a strip or length of dielectric material or other coupler. The electromagnetic field structure of the guided wave can be inside and/or outside of the coupler. When this coupler is brought into close proximity to a transmission medium (e.g., a wire, utility line or other transmission medium), at least a portion of the guided wave decouples from the waveguide and couples to the transmission medium, and continues to propagate as guided waves, such as surface waves about the surface of the wire.

In one or more embodiments, a coupler includes a receiving portion that receives a first electromagnetic wave conveying first data from a transmitting device. A guiding portion guides the first electromagnetic wave to a junction for coupling the first electromagnetic wave to a transmission medium. The first electromagnetic wave propagates via at least one first guided wave mode. The coupling of the first electromagnetic wave to the transmission medium forms a second electromagnetic wave that is guided to propagate along the outer surface of the transmission medium via at least one second guided wave mode that differs from the at least one first guided wave mode.

In one or more embodiments, a coupling module includes a plurality of receiving portions that receive a corresponding plurality of first electromagnetic waves conveying first data. A plurality of guiding portions guide the plurality of first electromagnetic waves to a corresponding plurality of junctions for coupling the plurality of first electromagnetic waves to a transmission medium. The plurality of first electromagnetic waves propagate via at least one first guided wave mode and the coupling of the plurality of first electromagnetic waves to the transmission medium forms a plurality of second electromagnetic waves that are guided to propagate along the outer surface of the transmission medium via at least one second guided wave mode that differs from the at least one first guided wave mode.

In one or more embodiments, a method includes receiving a first electromagnetic wave conveying first data from a transmitting device. The first electromagnetic wave is guided to a junction for coupling the first electromagnetic wave to a transmission medium. The first electromagnetic wave propagates via at least one first guided wave mode and the coupling of the first electromagnetic wave to the transmission medium forms a second electromagnetic wave that is guided to propagate along the outer surface of the transmission medium via at least one second guided wave mode that differs from the at least one first guided wave mode.

In one or more embodiments, a transmission device includes a first coupler that guides a first electromagnetic wave to a first junction to form a second electromagnetic wave that is guided to propagate along the outer surface of the transmission medium via one or more guided wave modes. This mode or modes have an envelope that varies as a function of angular deviation and/or longitudinal displacement. A second coupler guides a third electromagnetic wave from a second junction coupling the third electromagnetic wave from the transmission medium. The second junction is arranged in angular deviation and/or longitudinal displacement to correspond to a local minimum of the envelope.

In one or more embodiments, a waveguide system includes a transmission device having a coupler positioned with respect to a transmission medium to facilitate transmission or reception of electromagnetic waves that transport communications data. The electromagnetic waves propagate along an outer surface of the transmission medium. A training controller detects an impairment on the transmission medium adverse to the transmission or reception of the electromagnetic waves and that adjusts an envelope of the electromagnetic waves to place a local minimum of the envelope in a location that corresponds to a position of the impairment on the transmission medium.

In one or more embodiments, a method includes facilitating transmission or reception of electromagnetic waves that propagate along an outer surface of a single wire transmission medium via a transmission device, wherein the electromagnetic waves transport communications data. An impairment is detected on the outer surface of the single wire transmission medium that is adverse to the transmission of the electromagnetic waves. An envelope the electromagnetic waves is adjusted to place a local minimum of the envelope in a location that corresponds to a position of the impairment on the outer surface of the single wire transmission medium.

According to an example embodiment, the electromagnetic wave is a surface wave, which is a type of guided wave that is guided by a surface of the transmission medium, which can include an exterior or outer surface of the wire, exterior or outer surface of dielectric coating or insulating jacket, or another surface of a transmission medium that is adjacent to or exposed to another type of medium having different properties (e.g., dielectric properties). Indeed, in an example embodiment, a surface of the transmission that guides a surface wave can represent a transitional surface between two different types of media. For example, in the case of a bare or uninsulated wire, the surface of the wire can be the outer or exterior conductive surface of the bare or uninsulated wire that is exposed to air or free space. As another example, in the case of insulated wire, the surface of the wire can be the conductive portion of the wire that meets the insulator portion of the wire, or can otherwise be the insulated surface of the wire that is exposed to air or free space, or can otherwise be any material region between the insulated surface of the wire and the conductive portion of the wire that meets the insulator portion of the wire, depending upon the relative differences in the properties (e.g., dielectric properties) of the insulator, air, and/or the conductor and further dependent on the frequency and propagation mode or modes of the guided wave.

According to an example embodiment, guided waves such as surface waves can be contrasted with radio transmissions over free space/air or conventional propagation of electrical power or signals through the conductor of the wire. Indeed, with surface wave or guided wave systems described herein, conventional electrical power or signals can still propagate or be transmitted through the conductor of the wire, while guided waves (including surface waves and other electromagnetic waves) can surround all or part of the surface of the wire and propagate along the wire with low loss, according to an example embodiment. In an example embodiment, a surface wave can have a field structure (e.g., an electromagnetic field structure) that lies primarily or substantially outside of the transmission medium that serves to guide the surface wave.

In an example embodiment, the guided waves employed herein can be contrasted with Sommerfeld waves used as a

means of propagation along a wire which are limited to waves having a wavelength greater than, not less than, the circumference of the wire. In an example embodiment, the guided waves employed herein can be contrasted with G-Wave and E-Wave systems that operate via the propagation of the fundamental mode and not based on the propagation of at least one asymmetric mode. In an example embodiment, the guided waves employed herein can be contrasted with surface plasmon wave propagation along single metal wire premised on the electron bunches that form in conductors at frequencies such as optical frequencies, well above, and not less than y, the mean collision frequency of electrons of the conducting material. These prior art systems have failed to address guided wave propagation for a transmission medium, where the guided wave includes an asymmetric mode that propagates at low loss frequencies, such as in the millimeter wave band, that are less than the mean collision frequency of electrons of the conducting material. These prior art systems have failed to address guided wave propagation for a transmission medium that includes an outer dielectric, where the guided wave includes an asymmetric mode that propagates with low loss with fields concentrated about the outer surface of the dielectric.

According to an example embodiment, the electromagnetic waves traveling along a wire are induced by other electromagnetic waves traveling along a waveguide in proximity to the wire. The inducement of the electromagnetic waves can be independent of any electrical potential, charge or current that is injected or otherwise transmitted through the wires as part of an electrical circuit. It is to be appreciated that while a small current in the wire may be formed in response to the propagation of the electromagnetic wave through the wire, this can be due to the propagation of the electromagnetic wave along the wire surface, and is not formed in response to electrical potential, charge or current that is injected into the wire as part of an electrical circuit. The electromagnetic waves traveling on the wire therefore do not require a circuit to propagate along the wire surface. The wire therefore is a single wire transmission line that does not require a circuit. Also, in some embodiments, a wire is not necessary, and the electromagnetic waves can propagate along a single line transmission medium that is not a wire.

According to an example embodiment, the term "single wire transmission medium" is used in conjunction with transmission via electromagnetic waves that are guided by a wire, but do not require the wire to be part of a circuit to support such propagation. A transmission system may include multiple single wire transmission media that act to transmit such guided waves, with different waves being guided by differing ones of the single wire transmission media.

According to an example embodiment, the term "about" a wire used in conjunction with a guided wave (e.g., surface wave) can include fundamental wave propagation modes and other guided waves having a circular or substantially circular field distribution (e.g., electric field, magnetic field, electromagnetic field, etc.) at least partially around a wire. In addition, when a guided wave propagates "about" a wire, it propagates longitudinally along the wire via a wave propagation mode (at least one guided wave mode) that can include not only the fundamental wave propagation modes (e.g., zero order modes), but additionally or alternatively other non-fundamental wave propagation modes such as higher-order guided wave modes (e.g., 1^{st} order modes, 2^{nd} order modes, etc.), asymmetrical modes and/or other guided (e.g., surface) waves that have non-circular field distributions around a wire.

For example, such non-circular field distributions can be unilateral or multi-lateral with one or more azimuthal lobes characterized by relatively higher field strength and/or one or more nulls or null regions characterized by relatively low-field strength, zero-field strength or substantially zero field strength. Further, the field distribution can otherwise vary as a function of a longitudinal azimuthal orientation around the wire such that one or more regions of azimuthal orientation around the wire have an electric or magnetic field strength (or combination thereof) that is higher than one or more other regions of azimuthal orientation, according to an example embodiment. It will be appreciated that the relative positions of the higher order modes or asymmetrical modes can vary as the guided wave travels along the wire.

Referring now to FIG. **1**, a block diagram illustrating an example, non-limiting embodiment of a guided wave communication system **100** is shown. Guided wave communication system **100** depicts an exemplary environment in which a transmission device, coupler or coupling module can be used.

Guided wave communication system **100** can be a distributed antenna system that includes one or more base station devices (e.g., base station device **104**) that are communicably coupled to a macrocell site **102** or other network connection. Base station device **104** can be connected by a wired (e.g., fiber and/or cable), or by a wireless (e.g., microwave wireless) connection to macrocell site **102**. Macrocells such as macrocell site **102** can have dedicated connections to the mobile network and base station device **104** can share and/or otherwise use macrocell site **102**'s connection. Base station device **104** can be mounted on, or attached to, utility pole **116**. In other embodiments, base station device **104** can be near transformers and/or other locations situated nearby a power line.

Base station device **104** can facilitate connectivity to a mobile network for mobile devices **122** and **124**. Antennas **112** and **114**, mounted on or near utility poles **118** and **120**, respectively, can receive signals from base station device **104** and transmit those signals to mobile devices **122** and **124** over a much wider area than if the antennas **112** and **114** were located at or near base station device **104**.

It is noted that FIG. **1** displays three utility poles, with one base station device, for purposes of simplicity. In other embodiments, utility pole **116** can have more base station devices, and one or more utility poles with distributed antennas are possible.

A transmission device, such as dielectric waveguide coupling device **106** can transmit the signal from base station device **104** to antennas **112** and **114** via utility or power line(s) that connect the utility poles **116**, **118**, and **120**. To transmit the signal, radio source and/or coupler **106** upconverts the signal (e.g., via frequency mixing) from base station device **104** or otherwise converts the signal from the base station device **104** to a millimeter-wave band signal having at least one carrier frequency in the millimeter wave frequency band. The dielectric waveguide coupling device **106** launches a millimeter-wave band wave that propagates as a guided wave (e.g., surface wave or other electromagnetic wave) traveling along the utility line or other wire. At utility pole **118**, another transmission device, such as dielectric waveguide coupling device **108** that receives the guided wave (and optionally can amplify it as needed or desired or operate as a digital repeater to receive it and regenerate it) and sends it forward as a guided wave (e.g., surface wave or other electromagnetic wave) on the utility line or other wire. The dielectric waveguide coupling device **108** can also extract a signal from the millimeter-wave band guided wave and shift it down in frequency or otherwise convert it to its original cellular band frequency (e.g., 1.9 GHz or other defined cellular frequency) or another cellular (or non-cellular) band frequency. An antenna **112** can

transmit (e.g., wirelessly transmit) the downshifted signal to mobile device **122**. The process can be repeated by another transmission device, such as dielectric waveguide coupling device **110**, antenna **114** and mobile device **124**, as necessary or desirable.

Transmissions from mobile devices **122** and **124** can also be received by antennas **112** and **114** respectively. Repeaters on dielectric waveguide coupling devices **108** and **110** can upshift or otherwise convert the cellular band signals to millimeter-wave band and transmit the signals as guided wave (e.g., surface wave or other electromagnetic wave) transmissions over the power line(s) to base station device **104**.

In an example embodiment, system **100** can employ diversity paths, where two or more utility lines or other wires are strung between the utility poles **116**, **118**, and **120** (e.g., two or more wires between poles **116** and **120**) and redundant transmissions from base station **104** are transmitted as guided waves down the surface of the utility lines or other wires. The utility lines or other wires can be either insulated or uninsulated, and depending on the environmental conditions that cause transmission losses, the coupling devices can selectively receive signals from the insulated or uninsulated utility lines or other wires. The selection can be based on measurements of the signal-to-noise ratio of the wires, or based on determined weather/environmental conditions (e.g., moisture detectors, weather forecasts, etc.). The use of diversity paths with system **100** can enable alternate routing capabilities, load balancing, increased load handling, concurrent bi-directional or synchronous communications, spread spectrum communications, etc. (See FIG. **8** for more illustrative details).

It is noted that the use of the dielectric waveguide coupling devices **106**, **108**, and **110** in FIG. **1** are by way of example only, and that in other embodiments, other uses are possible. For instance, dielectric waveguide coupling devices can be used in a backhaul communication system, providing network connectivity to base station devices. Dielectric waveguide coupling devices can be used in many circumstances where it is desirable to transmit guided wave communications over a wire, whether insulated or not insulated. Dielectric waveguide coupling devices are improvements over other coupling devices due to no contact or limited physical and/or electrical contact with the wires that may carry high voltages. With dielectric waveguide coupling devices, the apparatus can be located away from the wire (e.g., spaced apart from the wire) and/or located on the wire so long as it is not electrically in contact with the wire, as the dielectric acts as an insulator, allowing for cheap, easy, and/or less complex installation. However, as previously noted conducting or non-dielectric couplers can be employed, particularly in configurations where the wires correspond to a telephone network, cable television network, broadband data service, fiber optic communications system or other network employing low voltages or having insulated transmission lines.

It is further noted, that while base station device **104** and macrocell site **102** are illustrated in an example embodiment, other network configurations are likewise possible. For example, devices such as access points or other wireless gateways can be employed in a similar fashion to extend the reach of other networks such as a wireless local area network, a wireless personal area network or other wireless network that operates in accordance with a communication protocol such as a 802.11 protocol, WIMAX protocol, UltraWideband protocol, Bluetooth protocol, Zigbee protocol or other wireless protocol.

Turning now to FIG. **2**, illustrated is a block diagram of an example, non-limiting embodiment of a dielectric waveguide coupling system **200** in accordance with various aspects described herein. System **200** comprises a dielectric waveguide **204** that has a wave **206** propagating as a guided wave about a waveguide surface of the dielectric waveguide **204**. In an example embodiment, the dielectric waveguide **204** is curved, and at least a portion of the dielectric waveguide **204** can be placed near a wire **202** in order to facilitate coupling between the dielectric waveguide **204** and the wire **202**, as described herein. The dielectric waveguide **204** can be placed such that a portion of the curved dielectric waveguide **204** is parallel or substantially parallel to the wire **202**. The portion of the dielectric waveguide **204** that is parallel to the wire can be an apex of the curve, or any point where a tangent of the curve is parallel to the wire **202**. When the dielectric waveguide **204** is positioned or placed thusly, the wave **206** travelling along the dielectric waveguide **204** couples, at least in part, to the wire **202**, and propagates as guided wave **208** around or about the wire surface of the wire **202** and longitudinally along the wire **202**. The guided wave **208** can be characterized as a surface wave or other electromagnetic wave, although other types of guided waves **208** can be supported as well without departing from example embodiments. A portion of the wave **206** that does not couple to the wire **202** propagates as wave **210** along the dielectric waveguide **204**. It will be appreciated that the dielectric waveguide **204** can be configured and arranged in a variety of positions in relation to the wire **202** to achieve a desired level of coupling or non-coupling of the wave **206** to the wire **202**. For example, the curvature and/or length of the dielectric waveguide **204** that is parallel or substantially parallel, as well as its separation distance (which can include zero separation distance in an example embodiment), to the wire **202** can be varied without departing from example embodiments. Likewise, the arrangement of the dielectric waveguide **204** in relation to the wire **202** may be varied based upon considerations of the respective intrinsic characteristics (e.g., thickness, composition, electromagnetic properties, etc.) of the wire **202** and the dielectric waveguide **204**, as well as the characteristics (e.g., frequency, energy level, etc.) of the waves **206** and **208**.

The guided wave **208** propagates in a direction parallel or substantially parallel to the wire **202**, even as the wire **202** bends and flexes. Bends in the wire **202** can increase transmission losses, which are also dependent on wire diameters, frequency, and materials. If the dimensions of the dielectric waveguide **204** are chosen for efficient power transfer, most of the power in the wave **206** is transferred to the wire **202**, with little power remaining in wave **210**. It will be appreciated that the guided wave **208** can still be multi-modal in nature (discussed herein), including having modes that are non-fundamental or asymmetric, while traveling along a path that is parallel or substantially parallel to the wire **202**, with or without a fundamental transmission mode. In an example embodiment, non-fundamental or asymmetric modes can be utilized to minimize transmission losses and/or obtain increased propagation distances.

It is noted that the term parallel is generally a geometric construct which often is not exactly achievable in real systems. Accordingly, the term parallel as utilized in the subject disclosure represents an approximation rather than an exact configuration when used to describe embodiments disclosed in the subject disclosure. In an example embodiment, substantially parallel can include approximations that are within 30 degrees of true parallel in all dimensions.

In an example embodiment, the wave **206** can exhibit one or more wave propagation modes. The dielectric waveguide modes can be dependent on the shape and/or design of the dielectric waveguide **204**. The one or more dielectric waveguide modes of wave **206** can generate, influence, or impact one or more wave propagation modes of the guided wave **208** propagating along wire **202**. In an example embodiment, the wave propagation modes on the wire **202** can be similar to the dielectric waveguide modes since both waves **206** and **208** propagate about the outside of the dielectric waveguide **204** and wire **202** respectively. In some embodiments, as the wave **206** couples to the wire **202**, the modes can change form due to the coupling between the dielectric waveguide **204** and the wire **202**. For example, differences in size, material, and/or impedances of the dielectric waveguide **204** and the wire **202** may create additional modes not present in the dielectric waveguide modes and/or suppress some of the dielectric waveguide modes. The wave propagation modes can comprise the fundamental transverse electromagnetic mode (Quasi-TEM_{00}), where only small electric and/or magnetic fields extend in the direction of propagation, and the electric and magnetic fields extend radially outwards while the guided wave propagates along the wire. This guided wave mode can be donut shaped, where few of the electromagnetic fields exist within the dielectric waveguide **204** or wire **202**. Waves **206** and **208** can comprise a fundamental TEM mode where the fields extend radially outwards, and also comprise other, non-fundamental (e.g., asymmetric, higher-level, etc.) modes. While particular wave propagation modes are discussed above, other wave propagation modes are likewise possible such as transverse electric (TE) and transverse magnetic (TM) modes, based on the frequencies employed, the design of the dielectric waveguide **204**, the dimensions and composition of the wire **202**, as well as its surface characteristics, its optional insulation, the electromagnetic properties of the surrounding environment, etc. It should be noted that, depending on the frequency, the electrical and physical characteristics of the wire **202** and the particular wave propagation modes that are generated, the guided wave **208** can travel along the conductive surface of an oxidized uninsulated wire, an unoxidized uninsulated wire, an insulated wire and/or along the insulating surface of an insulated wire.

In an example embodiment, a diameter of the dielectric waveguide **204** is smaller than the diameter of the wire **202**. For the millimeter-band wavelength being used, the dielectric waveguide **204** supports a single waveguide mode that makes up wave **206**. This single waveguide mode can change as it couples to the wire **202** as surface wave **208**. If the dielectric waveguide **204** were larger, more than one waveguide mode can be supported, but these additional waveguide modes may not couple to the wire **202** as efficiently, and higher coupling losses can result. However, in some alternative embodiments, the diameter of the dielectric waveguide **204** can be equal to or larger than the diameter of the wire **202**, for example, where higher coupling losses are desirable or when used in conjunction with other techniques to otherwise reduce coupling losses (e.g., impedance matching with tapering, etc.).

In an example embodiment, the wavelength of the waves **206** and **208** are comparable in size, or smaller than a circumference of the dielectric waveguide **204** and the wire **202**. In an example, if the wire **202** has a diameter of 0.5 cm, and a corresponding circumference of around 1.5 cm, the wavelength of the transmission is around 1.5 cm or less, corresponding to a frequency of 20 GHz or greater. In another embodiment, a suitable frequency of the transmission and the carrier-wave signal is in the range of 30-100 GHz, perhaps around 30-60 GHz, and around 38 GHz in one example. In an example embodiment, when the circumference of the dielectric waveguide **204** and wire **202** is comparable in size to, or greater, than a wavelength of the transmission, the waves **206** and **208** can exhibit multiple wave propagation modes including fundamental and/or non-fundamental (symmetric and/or asymmetric) modes that propagate over sufficient distances to support various communication systems described herein. The waves **206** and **208** can therefore comprise more than one type of electric and magnetic field configuration. In an example embodiment, as the guided wave **208** propagates down the wire **202**, the electrical and magnetic field configurations will remain the same from end to end of the wire **202**. In other embodiments, as the guided wave **208** encounters interference or loses energy due to transmission losses, the electric and magnetic field configurations can change as the guided wave **208** propagates down wire **202**.

In an example embodiment, the dielectric waveguide **204** can be composed of nylon, Teflon, polyethylene, a polyamide, or other plastics. In other embodiments, other dielectric materials are possible. The wire surface of wire **202** can be metallic with either a bare metallic surface, or can be insulated using plastic, dielectric, insulator or other sheathing. In an example embodiment, a dielectric or otherwise non-conducting/insulated waveguide can be paired with either a bare/metallic wire or insulated wire. In other embodiments, a metallic and/or conductive waveguide can be paired with a bare/metallic wire or insulated wire. In an example embodiment, an oxidation layer on the bare metallic surface of the wire **202** (e.g., resulting from exposure of the bare metallic surface to oxygen/air) can also provide insulating or dielectric properties similar to those provided by some insulators or sheathings.

It is noted that the graphical representations of waves **206**, **208** and **210** are presented merely to illustrate the principles that wave **206** induces or otherwise launches a guided wave **208** on a wire **202** that operates, for example, as a single wire transmission line. Wave **210** represents the portion of wave **206** that remains on the dielectric waveguide **204** after the generation of guided wave **208**. The actual electric and magnetic fields generated as a result of such wave propagation may vary depending on the frequencies employed, the particular wave propagation mode or modes, the design of the dielectric waveguide **204**, the dimensions and composition of the wire **202**, as well as its surface characteristics, its optional insulation, the electromagnetic properties of the surrounding environment, etc.

It is noted that dielectric waveguide **204** can include a termination circuit or damper **214** at the end of the dielectric waveguide **204** that can absorb leftover radiation or energy from wave **210**. The termination circuit or damper **214** can prevent and/or minimize the leftover radiation from wave **210** reflecting back toward transmitter circuit **212**. In an example embodiment, the termination circuit or damper **214** can include termination resistors, and/or other components that perform impedance matching to attenuate reflection. In some embodiments, if the coupling efficiencies are high enough, and/or wave **210** is sufficiently small, it may not be necessary to use a termination circuit or damper **214**. For the sake of simplicity, these transmitter and termination circuits or dampers **212** and **214** are not depicted in the other figures, but in those embodiments, transmitter and termination circuits or dampers may possibly be used.

Further, while a single dielectric waveguide **204** is presented that generates a single guided wave **208**, multiple dielectric waveguides **204** placed at different points along the wire **202** and/or at different azimuthal orientations about the wire can be employed to generate and receive multiple guided

waves **208** at the same or different frequencies, at the same or different phases, and/or at the same or different wave propagation modes. The guided wave or waves **208** can be modulated to convey data via a modulation technique such as phase shift keying, frequency shift keying, quadrature amplitude modulation, amplitude modulation, multi-carrier modulation and via multiple access techniques such as frequency division multiplexing, time division multiplexing, code division multiplexing, multiplexing via differing wave propagation modes and via other modulation and access strategies.

Turning now to FIG. **3**, illustrated is a block diagram of an example, non-limiting embodiment of a dielectric waveguide coupling system **300** in accordance with various aspects described herein. System **300** implements a coupler that comprises a dielectric waveguide **304** and a wire **302** that has a wave **306** propagating as a guided wave about a wire surface of the wire **302**. In an example embodiment, the wave **306** can be characterized as a surface wave or other electromagnetic wave.

In an example embodiment, the dielectric waveguide **304** is curved or otherwise has a curvature, and can be placed near a wire **302** such that a portion of the curved dielectric waveguide **304** is parallel or substantially parallel to the wire **302**. The portion of the dielectric waveguide **304** that is parallel to the wire can be an apex of the curve, or any point where a tangent of the curve is parallel to the wire **302**. When the dielectric waveguide **304** is near the wire, the guided wave **306** travelling along the wire **302** can couple to the dielectric waveguide **304** and propagate as guided wave **308** about the dielectric waveguide **304**. A portion of the guided wave **306** that does not couple to the dielectric waveguide **304** propagates as guided wave **310** (e.g., surface wave or other electromagnetic wave) along the wire **302**.

The guided waves **306** and **308** stay parallel to the wire **302** and dielectric waveguide **304**, respectively, even as the wire **302** and dielectric waveguide **304** bend and flex. Bends can increase transmission losses, which are also dependent on wire diameters, frequency, and materials. If the dimensions of the dielectric waveguide **304** are chosen for efficient power transfer, most of the energy in the guided wave **306** is coupled to the dielectric waveguide **304** and little remains in guided wave **310**.

In an example embodiment, a receiver circuit can be placed on the end of waveguide **304** in order to receive wave **308**. A termination circuit can be placed on the opposite end of the waveguide **304** in order to receive guided waves traveling in the opposite direction to guided wave **306** that couple to the waveguide **304**. The termination circuit would thus prevent and/or minimize reflections being received by the receiver circuit. If the reflections are small, the termination circuit may not be necessary.

It is noted that the dielectric waveguide **304** can be configured such that selected polarizations of the surface wave **306** are coupled to the dielectric waveguide **304** as guided wave **308**. For instance, if guided wave **306** is made up of guided waves or wave propagation modes with respective polarizations, dielectric waveguide **304** can be configured to receive one or more guided waves of selected polarization(s). Guided wave **308** that couples to the dielectric waveguide **304** is thus the set of guided waves that correspond to one or more of the selected polarization(s), and further guided wave **310** can comprise the guided waves that do not match the selected polarization(s).

The dielectric waveguide **304** can be configured to receive guided waves of a particular polarization based on an angle/rotation around the wire **302** that the dielectric waveguide **304** is placed (the azimuthal orientation of the coupler) and the azimuthal pattern of the field structure of the guided waves. For instance, if the coupler is oriented to feed the guided waves along the horizontal access and if the guided wave **306** is polarized horizontally (i.e., the filed structure of the guided waves are concentrated on the horizontal axis), most of the guided wave **306** transfers to the dielectric waveguide as wave **308**. In another instance, if the dielectric waveguide **304** is rotated 90 degrees around the wire **302**, most of the energy from guided wave **306** would remain coupled to the wire as guided wave **310**, and only a small portion would couple to the wire **302** as wave **308**.

It is noted that waves **306**, **308**, and **310** are shown using three circular symbols in FIG. **3** and in other figures in the specification. These symbols are used to represent a general guided wave, but do not imply that the waves **306**, **308**, and **310** are necessarily circularly polarized or otherwise circularly oriented. In fact, waves **306**, **308**, and **310** can comprise a fundamental TEM mode where the fields extend radially outwards, and also comprise other, non-fundamental (e.g. higher-level, etc.) modes. These modes can be asymmetric (e.g., radial, bilateral, trilateral, quadrilateral, etc,) in nature as well.

It is noted also that guided wave communications over wires can be full duplex, allowing simultaneous communications in both directions. Waves traveling one direction can pass through waves traveling in an opposite direction. Electromagnetic fields may cancel out at certain points and for short times due to the superposition principle as applied to waves. The waves traveling in opposite directions propagate as if the other waves weren't there, but the composite effect to an observer may be a stationary standing wave pattern. As the guided waves pass through each other and are no longer in a state of superposition, the interference subsides. As a guided wave (e.g., surface wave or other electromagnetic wave) couples to a waveguide and moves away from the wire, any interference due to other guided waves (e.g., surface waves or other electromagnetic waves) decreases. In an example embodiment, as guided wave **306** (e.g., surface wave or other electromagnetic wave) approaches dielectric waveguide **304**, another guided wave (e.g., surface wave or other electromagnetic wave) (not shown) traveling from left to right on the wire **302** passes by causing local interference. As guided wave **306** couples to dielectric waveguide **304** as wave **308**, and moves away from the wire **302**, any interference due to the passing guided wave subsides.

It is noted that the graphical representations of electromagnetic waves **306**, **308** and **310** are presented merely to illustrate the principles that guided wave **306** induces or otherwise launches a wave **308** on a dielectric waveguide **304**. Guided wave **310** represents the portion of guided wave **306** that remains on the wire **302** after the generation of wave **308**. The actual electric and magnetic fields generated as a result of such guided wave propagation may vary depending on one or more of the shape and/or design of the dielectric waveguide, the relative position of the dielectric waveguide to the wire, the frequencies employed, the design of the dielectric waveguide **304**, the dimensions and composition of the wire **302**, as well as its surface characteristics, its optional insulation, the electromagnetic properties of the surrounding environment, etc.

Turning now to FIG. **4**, illustrated is a block diagram of an example, non-limiting embodiment of a dielectric waveguide coupling system **400** in accordance with various aspects described herein. System **400** implements a coupler that comprises a dielectric waveguide **404** that has a wave **406** propagating as a guided wave about a waveguide surface of the dielectric waveguide **404**. In an example embodiment, the

dielectric waveguide **404** is curved, and an end of the dielectric waveguide **404** can be tied, fastened, or otherwise mechanically coupled to a wire **402**. When the end of the dielectric waveguide **404** is fastened to the wire **402**, the end of the dielectric waveguide **404** is parallel or substantially parallel to the wire **402**. Alternatively, another portion of the dielectric waveguide beyond an end can be fastened or coupled to wire **402** such that the fastened or coupled portion is parallel or substantially parallel to the wire **402**. The coupling device **410** can be a nylon cable tie or other type of non-conducting/dielectric material that is either separate from the dielectric waveguide **404** or constructed as an integrated component of the dielectric waveguide **404**. In other embodiments, the dielectric waveguide **404** can be mechanically uncoupled from the wire **402** leaving an air gap between the coupler and the wire **402**. The dielectric waveguide **404** can be adjacent to the wire **402** without surrounding the wire **402**.

When the dielectric waveguide **404** is placed with the end parallel to the wire **402**, the guided wave **406** travelling along the dielectric waveguide **404** couples to the wire **402**, and propagates as guided wave **408** about the wire surface of the wire **402**. In an example embodiment, the guided wave **408** can be characterized as a surface wave or other electromagnetic wave.

It is noted that the graphical representations of waves **406** and **408** are presented merely to illustrate the principles that wave **406** induces or otherwise launches a guided wave **408** on a wire **402** that operates, for example, as a single wire transmission line. The actual electric and magnetic fields generated as a result of such wave propagation may vary depending on one or more of the shape and/or design of the dielectric waveguide, the relative position of the dielectric waveguide to the wire, the frequencies employed, the design of the dielectric waveguide **404**, the dimensions and composition of the wire **402**, as well as its surface characteristics, its optional insulation, the electromagnetic properties of the surrounding environment, etc.

In an example embodiment, an end of dielectric waveguide **404** can taper towards the wire **402** in order to increase coupling efficiencies. Indeed, the tapering of the end of the dielectric waveguide **404** can provide impedance matching to the wire **402**, according to an example embodiment of the subject disclosure. For example, an end of the dielectric waveguide **404** can be gradually tapered in order to obtain a desired level of coupling between waves **406** and **408** as illustrated in FIG. **4**.

In an example embodiment, the coupling device **410** can be placed such that there is a short length of the dielectric waveguide **404** between the coupling device **410** and an end of the dielectric waveguide **404**. Maximum coupling efficiencies are realized when the length of the end of the dielectric waveguide **404** that is beyond the coupling device **410** is at least several wavelengths long for whatever frequency is being transmitted, however shorter lengths are also possible.

Turning now to FIG. **5**, illustrated is a block diagram of an example, non-limiting embodiment of a dielectric waveguide coupler and transceiver system **500** (referred to herein collectively as system **500**) in accordance with various aspects described herein. System **500** implements a transmission device with a coupler that comprises a transmitter/receiver device **506** that launches and receives waves (e.g., guided wave **504** onto dielectric waveguide **502**). The guided waves **504** can be used to transport signals received from and sent to a base station device **508**, mobile devices **522**, or a building **524** by way of a communications interface **501**. The communications interface **501** can be an integral part of system **500**. Alternatively, the communications interface **501** can be tethered to system **500**. The communications interface **501** can comprise a wireless interface for interfacing to the base station **508**, the mobile devices **522**, or building **524** utilizing any of various wireless signaling protocols (e.g., LTE, WiFi, WiMAX, etc.). The communications interface **501** can also comprise a wired interface such as a fiber optic line, coaxial cable, twisted pair, or other suitable wired mediums for transmitting signals to the base station **508** or building **524**. For embodiments where system **500** functions as a repeater, the communications interface **501** may not be necessary.

The output signals (e.g., TX) of the communications interface **501** can be combined with a millimeter-wave carrier wave generated by a local oscillator **512** at frequency mixer **510**. Frequency mixer **510** can use heterodyning techniques or other frequency shifting techniques to frequency shift the output signals from communications interface **501**. For example, signals sent to and from the communications interface **501** can be modulated signals such as orthogonal frequency division multiplexed (OFDM) signals formatted in accordance with a Long-Term Evolution (LTE) wireless protocol or other wireless 3G, 4G, 5G or higher voice and data protocol, a Zigbee, WIMAX, UltraWideband or IEEE 802.11 wireless protocol or other wireless protocol. In an example embodiment, this frequency conversion can be done in the analog domain, and as a result, the frequency shifting can be done without regard to the type of communications protocol that the base station **508**, mobile devices **522**, or in-building devices **524** use. As new communications technologies are developed, the communications interface **501** can be upgraded or replaced and the frequency shifting and transmission apparatus can remain, simplifying upgrades. The carrier wave can then be sent to a power amplifier ("PA") **514** and can be transmitted via the transmitter receiver device **506** via the diplexer **516**.

Signals received from the transmitter/receiver device **506** that are directed towards the communications interface **501** can be separated from other signals via diplexer **516**. The transmission can then be sent to low noise amplifier ("LNA") **518** for amplification. A frequency mixer **520**, with help from local oscillator **512** can downshift the transmission (which is in the millimeter-wave band or around 38 GHz in some embodiments) to the native frequency. The communications interface **501** can then receive the transmission at an input port (RX).

In an embodiment, transmitter/receiver device **506** can include a cylindrical or non-cylindrical metal (which, for example, can be hollow in an embodiment, but not necessarily drawn to scale) or other conducting or non-conducting waveguide and an end of the dielectric waveguide **502** can be placed in or in proximity to the waveguide or the transmitter/receiver device **506** such that when the transmitter/receiver device **506** generates a transmission, the guided wave couples to dielectric waveguide **502** and propagates as a guided wave **504** about the waveguide surface of the dielectric waveguide **502**. In some embodiments, the guided wave **504** can propagate in part on the outer surface of the dielectric waveguide **502** and in part inside the dielectric waveguide **502**. In other embodiments, the guided wave **504** can propagate substantially or completely on the outer surface of the dielectric waveguide **502**. In yet other embodiments, the guided wave **504** can propagate substantially or completely inside the dielectric waveguide **502**. In this latter embodiment, the guide wave **504** can radiate at an end of the dielectric waveguide **502** (such as the tapered end shown in FIG. **4**) for coupling to a transmission medium such as a wire **402** of FIG. **4**. Similarly, if guided wave **504** is incoming (coupled to the dielectric

waveguide **502** from a wire), guided wave **504** then enters the transmitter/receiver device **506** and couples to the cylindrical waveguide or conducting waveguide. While transmitter/receiver device **506** is shown to include a separate waveguide—an antenna, cavity resonator, klystron, magnetron, travelling wave tube, or other radiating element can be employed to induce a guided wave on the waveguide **502**, without the separate waveguide.

In an embodiment, dielectric waveguide **502** can be wholly constructed of a dielectric material (or another suitable insulating material), without any metallic or otherwise conducting materials therein. Dielectric waveguide **502** can be composed of nylon, Teflon, polyethylene, a polyamide, other plastics, or other materials that are non-conducting and suitable for facilitating transmission of electromagnetic waves at least in part on an outer surface of such materials. In another embodiment, dielectric waveguide **502** can include a core that is conducting/metallic, and have an exterior dielectric surface. Similarly, a transmission medium that couples to the dielectric waveguide **502** for propagating electromagnetic waves induced by the dielectric waveguide **502** or for supplying electromagnetic waves to the dielectric waveguide **502** can be wholly constructed of a dielectric material (or another suitable insulating material), without any metallic or otherwise conducting materials therein.

It is noted that although FIG. **5**A shows that the opening of transmitter receiver device **506** is much wider than the dielectric waveguide **502**, this is not to scale, and that in other embodiments the width of the dielectric waveguide **502** is comparable or slightly smaller than the opening of the hollow waveguide. It is also not shown, but in an embodiment, an end of the waveguide **502** that is inserted into the transmitter/receiver device **506** tapers down in order to reduce reflection and increase coupling efficiencies.

The transmitter/receiver device **506** can be communicably coupled to a communications interface **501**, and alternatively, transmitter/receiver device **506** can also be communicably coupled to the one or more distributed antennas **112** and **114** shown in FIG. **1**. In other embodiments, transmitter receiver device **506** can comprise part of a repeater system for a backhaul network.

Before coupling to the dielectric waveguide **502**, the one or more waveguide modes of the guided wave generated by the transmitter/receiver device **506** can couple to the dielectric waveguide **502** to induce one or more wave propagation modes of the guided wave **504**. The wave propagation modes of the guided wave **504** can be different than the hollow metal waveguide modes due to the different characteristics of the hollow metal waveguide and the dielectric waveguide. For instance, wave propagation modes of the guide wave **504** can comprise the fundamental transverse electromagnetic mode (Quasi-TEM_{00}), where only small electrical and/or magnetic fields extend in the direction of propagation, and the electric and magnetic fields extend radially outwards from the dielectric waveguide **502** while the guided waves propagate along the dielectric waveguide **502**. The fundamental transverse electromagnetic mode wave propagation mode may not exist inside a waveguide that is hollow. Therefore, the hollow metal waveguide modes that are used by transmitter/receiver device **506** are waveguide modes that can couple effectively and efficiently to wave propagation modes of dielectric waveguide **502**.

Turning now to FIG. **6**, illustrated is a block diagram illustrating an example, non-limiting embodiment of a dual dielectric waveguide coupling system **600** in accordance with various aspects described herein. In an example embodiment, a coupling module is shown with two or more dielectric waveguides (e.g., **604** and **606**) positioned around a wire **602** in order to receive guided wave **608**. In an example embodiment, the guided wave **608** can be characterized as a surface wave or other electromagnetic wave. In an example embodiment, one dielectric waveguide is enough to receive the guided wave **608**. In that case, guided wave **608** couples to dielectric waveguide **604** and propagates as guided wave **610**. If the field structure of the guided wave **608** oscillates or undulates around the wire **602** due to various outside factors, then dielectric waveguide **606** can be placed such that guided wave **608** couples to dielectric waveguide **606**. In some embodiments, four or more dielectric waveguides can be placed around a portion of the wire **602**, e.g., at 90 degrees or another spacing with respect to each other, in order to receive guided waves that may oscillate or rotate around the wire **602**, that have been induced at different azimuthal orientations or that have non-fundamental or higher order modes that, for example, have lobes and/or nulls or other asymmetries that are orientation dependent. However, it will be appreciated that there may be less than or more than four dielectric waveguides placed around a portion of the wire **602** without departing from example embodiments. It will also be appreciated that while some example embodiments have presented a plurality of dielectric waveguides around at least a portion of a wire **602**, this plurality of dielectric waveguides can also be considered as part of a single dielectric waveguide system having multiple dielectric waveguide subcomponents. For example, two or more dielectric waveguides can be manufactured as single system that can be installed around a wire in a single installation such that the dielectric waveguides are either pre-positioned or adjustable relative to each other (either manually or automatically) in accordance with the single system. Receivers coupled to dielectric waveguides **606** and **604** can use diversity combining to combine signals received from both dielectric waveguides **606** and **604** in order to maximize the signal quality. In other embodiments, if one or the other of a dielectric waveguide **604** and **606** receives a transmission that is above a predetermined threshold, receivers can use selection diversity when deciding which signal to use.

It is noted that the graphical representations of waves **608** and **610** are presented merely to illustrate the principles that guided wave **608** induces or otherwise launches a wave **610** on a dielectric waveguide **604**. The actual electric and magnetic fields generated as a result of such wave propagation may vary depending on the frequencies employed, the design of the dielectric waveguide **604**, the dimensions and composition of the wire **602**, as well as its surface characteristics, its optional insulation, the electromagnetic properties of the surrounding environment, etc.

Turning now to FIG. **7**, illustrated is a block diagram of an example, non-limiting embodiment of a bidirectional dielectric waveguide coupling system **700** in accordance with various aspects described herein. Such a system **700** implements a transmission device with a coupling module that includes two dielectric waveguides **704** and **714** can be placed near a wire **702** such that guided waves (e.g., surface waves or other electromagnetic waves) propagating along the wire **702** are coupled to dielectric waveguide **704** as wave **706**, and then are boosted or repeated by repeater device **710** and launched as a guided wave **716** onto dielectric waveguide **714**. The guided wave **716** can then couple to wire **702** and continue to propagate along the wire **702**. In an example embodiment, the repeater device **710** can receive at least a portion of the power utilized for boosting or repeating through magnetic coupling with the wire **702**, which can be a power line.

In some embodiments, repeater device **710** can repeat the transmission associated with wave **706**, and in other embodiments, repeater device **710** can be associated with a distributed antenna system and/or base station device located near the repeater device **710**. Receiver waveguide **708** can receive the wave **706** from the dielectric waveguide **704** and transmitter waveguide **712** can launch guided wave **716** onto dielectric waveguide **714**. Between receiver waveguide **708** and transmitter waveguide **712**, the signal can be amplified to correct for signal loss and other inefficiencies associated with guided wave communications or the signal can be received and processed to extract the data contained therein and regenerated for transmission. In an example embodiment, a signal can be extracted from the transmission and processed and otherwise emitted to mobile devices nearby via distributed antennas communicably coupled to the repeater device **710**. Similarly, signals and/or communications received by the distributed antennas can be inserted into the transmission that is generated and launched onto dielectric waveguide **714** by transmitter waveguide **712**. Accordingly, the repeater system **700** depicted in FIG. **7** can be comparable in function to the dielectric waveguide coupling device **108** and **110** in FIG. **1**.

It is noted that although FIG. **7** shows guided wave transmissions **706** and **716** entering from the left and exiting to the right respectively, this is merely a simplification and is not intended to be limiting. In other embodiments, receiver waveguide **708** and transmitter waveguide **712** can also function as transmitters and receivers respectively, allowing the repeater device **710** to be bi-directional.

In an example embodiment, repeater device **710** can be placed at locations where there are discontinuities or obstacles on the wire **702**. These obstacles can include transformers, connections, utility poles, and other such power line devices. The repeater device **710** can help the guided (e.g., surface) waves jump over these obstacles on the line and boost the transmission power at the same time. In other embodiments, a dielectric waveguide can be used to jump over the obstacle without the use of a repeater device. In that embodiment, both ends of the dielectric waveguide can be tied or fastened to the wire, thus providing a path for the guided wave to travel without being blocked by the obstacle.

Turning now to FIG. **8**, illustrated is a block diagram of an example, non-limiting embodiment of a bidirectional dielectric waveguide coupler **800** in accordance with various aspects described herein. The bidirectional dielectric waveguide coupler **800** implements a transmission device with a coupling module that can employ diversity paths in the case of when two or more wires are strung between utility poles. Since guided wave transmissions have different transmission efficiencies and coupling efficiencies for insulated wires and un-insulated wires based on weather, precipitation and atmospheric conditions, it can be advantageous to selectively transmit on either an insulated wire or un-insulated wire at certain times.

In the embodiment shown in FIG. **8**, the repeater device uses a receiver waveguide **808** to receive a guided wave traveling along uninsulated wire **802** and repeats the transmission using transmitter waveguide **810** as a guided wave along insulated wire **804**. In other embodiments, repeater device can switch from the insulated wire **804** to the uninsulated wire **802**, or can repeat the transmissions along the same paths. Repeater device **806** can include sensors, or be in communication with sensors that indicate conditions that can affect the transmission. Based on the feedback received from the sensors, the repeater device **806** can make the determination about whether to keep the transmission along the same wire, or transfer the transmission to the other wire.

Turning now to FIG. **9**, illustrated is a block diagram illustrating an example, non-limiting embodiment of a bidirectional repeater system **900**. Bidirectional repeater system **900** implements a transmission device with a coupling module that includes waveguide coupling devices **902** and **904** that receive and transmit transmissions from other coupling devices located in a distributed antenna system or backhaul system.

In various embodiments, waveguide coupling device **902** can receive a transmission from another waveguide coupling device, wherein the transmission has a plurality of subcarriers. Diplexer **906** can separate the transmission from other transmissions, for example by filtration, and direct the transmission to low-noise amplifier ("LNA") **908**. A frequency mixer **928**, with help from a local oscillator **912**, can downshift the transmission (which is in the millimeter-wave band or around 38 GHz in some embodiments) to a lower frequency, whether it is a cellular band (~1.9 GHz) for a distributed antenna system, a native frequency, or other frequency for a backhaul system. An extractor **932** can extract the signal on the subcarrier that corresponds to the antenna or other output component **922** and direct the signal to the output component **922**. For the signals that are not being extracted at this antenna location, extractor **932** can redirect them to another frequency mixer **936**, where the signals are used to modulate a carrier wave generated by local oscillator **914**. The carrier wave, with its subcarriers, is directed to a power amplifier ("PA") **916** and is retransmitted by waveguide coupling device **904** to another repeater system, via diplexer **920**.

At the output device **922**, a PA **924** can boost the signal for transmission to the mobile device. An LNA **926** can be used to amplify weak signals that are received from the mobile device and then send the signal to a multiplexer **934** which merges the signal with signals that have been received from waveguide coupling device **904**. The output device **922** can be coupled to an antenna in a distributed antenna system or other antenna via, for example, a diplexer, duplexer or a transmit receive switch not specifically shown. The signals received from coupling device **904** have been split by diplexer **920**, and then passed through LNA **918**, and downshifted in frequency by frequency mixer **938**. When the signals are combined by multiplexer **934**, they are upshifted in frequency by frequency mixer **930**, and then boosted by PA **910**, and transmitted back to the launcher or on to another repeater by waveguide coupling device **902**. In an example embodiment, the bidirectional repeater system **900** can be just a repeater without the antenna/output device **922**. It will be appreciated that in some embodiments, a bidirectional repeater system **900** could also be implemented using two distinct and separate uni-directional repeaters. In an alternative embodiment, a bidirectional repeater system **900** could also be a booster or otherwise perform retransmissions without downshifting and upshifting. Indeed in example embodiment, the retransmissions can be based upon receiving a signal or guided wave and performing some signal or guided wave processing or reshaping, filtering, and/or amplification, prior to retransmission of the signal or guided wave.

FIG. **10** illustrates a process in connection with the aforementioned systems. The process in FIG. **10** can be implemented for example by systems **100**, **200**, **300**, **400**, **500**, **600**, **700**, **800**, and **900** illustrated in FIGS. **1-9** respectively. While for purposes of simplicity of explanation, the methods are shown and described as a series of blocks, it is to be understood and appreciated that the claimed subject matter is not limited by the order of the blocks, as some blocks may occur in different orders and/or concurrently with other blocks from

what is depicted and described herein. Moreover, not all illustrated blocks may be required to implement the methods described hereinafter.

FIG. **10** illustrates a flow diagram of an example, non-limiting embodiment of a method for transmitting a transmission with a dielectric waveguide coupler as described herein. Method **1000** can begin at **1002** where a first electromagnetic wave is emitted by a transmission device that propagates at least in part on a waveguide surface of a waveguide, wherein the waveguide surface of the waveguide does not surround in whole or in substantial part a wire surface of a wire. The transmission that is generated by a transmitter can be based on a signal received from a base station device, access point, network or a mobile device.

At **1004**, based upon configuring the waveguide in proximity of the wire, the guided wave then couples at least a part of the first electromagnetic wave to a wire surface, forming a second electromagnetic wave (e.g., a surface wave) that propagates at least partially around the wire surface, wherein the wire is in proximity to the waveguide. This can be done in response to positioning a portion of the dielectric waveguide (e.g., a tangent of a curve of the dielectric waveguide) near and parallel to the wire, wherein a wavelength of the electromagnetic wave is smaller than a circumference of the wire and the dielectric waveguide. The guided wave, or surface wave, stays parallel to the wire even as the wire bends and flexes. Bends can increase transmission losses, which are also dependent on wire diameters, frequency, and materials. The coupling interface between the wire and the waveguide can also be configured to achieve the desired level of coupling, as described herein, which can include tapering an end of the waveguide to improve impedance matching between the waveguide and the wire.

The transmission that is emitted by the transmitter can exhibit one or more waveguide modes. The waveguide modes can be dependent on the shape and/or design of the waveguide. The propagation modes on the wire can be different than the waveguide modes due to the different characteristics of the waveguide and the wire. When the circumference of the wire is comparable in size to, or greater, than a wavelength of the transmission, the guided wave exhibits multiple wave propagation modes. The guided wave can therefore comprise more than one type of electric and magnetic field configuration. As the guided wave (e.g., surface wave) propagates down the wire, the electrical and magnetic field configurations may remain substantially the same from end to end of the wire or vary as the transmission traverses the wave by rotation, dispersion, attenuation or other effects.

Referring now to FIG. **11**, there is illustrated a block diagram of a computing environment in accordance with various aspects described herein. In order to provide additional context for various embodiments of the embodiments described herein, FIG. **11** and the following discussion are intended to provide a brief, general description of a suitable computing environment **1100** in which the various embodiments of the embodiment described herein can be implemented. While the embodiments have been described above in the general context of computer-executable instructions that can be run on one or more computers, those skilled in the art will recognize that the embodiments can be also implemented in combination with other program modules and/or as a combination of hardware and software.

Generally, program modules comprise routines, programs, components, data structures, etc., that perform particular tasks or implement particular abstract data types. Moreover, those skilled in the art will appreciate that the inventive methods can be practiced with other computer system configurations, comprising single-processor or multiprocessor computer systems, minicomputers, mainframe computers, as well as personal computers, hand-held computing devices, microprocessor-based or programmable consumer electronics, and the like, each of which can be operatively coupled to one or more associated devices.

The terms "first," "second," "third," and so forth, as used in the claims, unless otherwise clear by context, is for clarity only and doesn't otherwise indicate or imply any order in time. For instance, "a first determination," "a second determination," and "a third determination," does not indicate or imply that the first determination is to be made before the second determination, or vice versa, etc.

The illustrated embodiments of the embodiments herein can be also practiced in distributed computing environments where certain tasks are performed by remote processing devices that are linked through a communications network. In a distributed computing environment, program modules can be located in both local and remote memory storage devices.

Computing devices typically comprise a variety of media, which can comprise computer-readable storage media and/or communications media, which two terms are used herein differently from one another as follows. Computer-readable storage media can be any available storage media that can be accessed by the computer and comprises both volatile and nonvolatile media, removable and non-removable media. By way of example, and not limitation, computer-readable storage media can be implemented in connection with any method or technology for storage of information such as computer-readable instructions, program modules, structured data or unstructured data.

Computer-readable storage media can comprise, but are not limited to, random access memory (RAM), read only memory (ROM), electrically erasable programmable read only memory (EEPROM), flash memory or other memory technology, compact disk read only memory (CD-ROM), digital versatile disk (DVD) or other optical disk storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices or other tangible and/or non-transitory media which can be used to store desired information. In this regard, the terms "tangible" or "non-transitory" herein as applied to storage, memory or computer-readable media, are to be understood to exclude only propagating transitory signals per se as modifiers and do not relinquish rights to all standard storage, memory or computer-readable media that are not only propagating transitory signals per se.

Computer-readable storage media can be accessed by one or more local or remote computing devices, e.g., via access requests, queries or other data retrieval protocols, for a variety of operations with respect to the information stored by the medium.

Communications media typically embody computer-readable instructions, data structures, program modules or other structured or unstructured data in a data signal such as a modulated data signal, e.g., a carrier wave or other transport mechanism, and comprises any information delivery or transport media. The term "modulated data signal" or signals refers to a signal that has one or more of its characteristics set or changed in such a manner as to encode information in one or more signals. By way of example, and not limitation, communication media comprise wired media, such as a wired network or direct-wired connection, and wireless media such as acoustic, RF, infrared and other wireless media.

With reference again to FIG. **11**, the example environment **1100** for transmitting and receiving signals via base station (e.g., base station devices **104** and **508**) and repeater devices (e.g., repeater devices **710**, **806**, and **900**) comprises a com-

puter **1102**, the computer **1102** comprising a processing unit **1104**, a system memory **1106** and a system bus **1108**. The system bus **1108** couples system components including, but not limited to, the system memory **1106** to the processing unit **1104**. The processing unit **1104** can be any of various commercially available processors. Dual microprocessors and other multi-processor architectures can also be employed as the processing unit **1104**.

The system bus **1108** can be any of several types of bus structure that can further interconnect to a memory bus (with or without a memory controller), a peripheral bus, and a local bus using any of a variety of commercially available bus architectures. The system memory **1106** comprises ROM **1110** and RAM **1112**. A basic input/output system (BIOS) can be stored in a non-volatile memory such as ROM, erasable programmable read only memory (EPROM), EEPROM, which BIOS contains the basic routines that help to transfer information between elements within the computer **1102**, such as during startup. The RAM **1112** can also comprise a high-speed RAM such as static RAM for caching data.

The computer **1102** further comprises an internal hard disk drive (HDD) **1114** (e.g., EIDE, SATA), which internal hard disk drive **1114** can also be configured for external use in a suitable chassis (not shown), a magnetic floppy disk drive (FDD) **1116**, (e.g., to read from or write to a removable diskette **1118**) and an optical disk drive **1120**, (e.g., reading a CD-ROM disk **1122** or, to read from or write to other high capacity optical media such as the DVD). The hard disk drive **1114**, magnetic disk drive **1116** and optical disk drive **1120** can be connected to the system bus **1108** by a hard disk drive interface **1124**, a magnetic disk drive interface **1126** and an optical drive interface **1128**, respectively. The interface **1124** for external drive implementations comprises at least one or both of Universal Serial Bus (USB) and Institute of Electrical and Electronics Engineers (IEEE) 1394 interface technologies. Other external drive connection technologies are within contemplation of the embodiments described herein.

The drives and their associated computer-readable storage media provide nonvolatile storage of data, data structures, computer-executable instructions, and so forth. For the computer **1102**, the drives and storage media accommodate the storage of any data in a suitable digital format. Although the description of computer-readable storage media above refers to a hard disk drive (HDD), a removable magnetic diskette, and a removable optical media such as a CD or DVD, it should be appreciated by those skilled in the art that other types of storage media which are readable by a computer, such as zip drives, magnetic cassettes, flash memory cards, cartridges, and the like, can also be used in the example operating environment, and further, that any such storage media can contain computer-executable instructions for performing the methods described herein.

A number of program modules can be stored in the drives and RAM **1112**, comprising an operating system **1130**, one or more application programs **1132**, other program modules **1134** and program data **1136**. All or portions of the operating system, applications, modules, and/or data can also be cached in the RAM **1112**. The systems and methods described herein can be implemented utilizing various commercially available operating systems or combinations of operating systems. Examples of application programs **1132** that can be implemented and otherwise executed by processing unit **1104** include the diversity selection determining performed by repeater device **806**. Base station device **508** shown in FIG. **5**, also has stored on memory many applications and programs that can be executed by processing unit **1104** in this exemplary computing environment **1100**.

A user can enter commands and information into the computer **1102** through one or more wired/wireless input devices, e.g., a keyboard **1138** and a pointing device, such as a mouse **1140**. Other input devices (not shown) can comprise a microphone, an infrared (IR) remote control, a joystick, a game pad, a stylus pen, touch screen or the like. These and other input devices are often connected to the processing unit **1104** through an input device interface **1142** that can be coupled to the system bus **1108**, but can be connected by other interfaces, such as a parallel port, an IEEE 1394 serial port, a game port, a universal serial bus (USB) port, an IR interface, etc.

A monitor **1144** or other type of display device can be also connected to the system bus **1108** via an interface, such as a video adapter **1146**. It will also be appreciated that in alternative embodiments, a monitor **1144** can also be any display device (e.g., another computer having a display, a smart phone, a tablet computer, etc.) for receiving display information associated with computer **1102** via any communication means, including via the Internet and cloud-based networks. In addition to the monitor **1144**, a computer typically comprises other peripheral output devices (not shown), such as speakers, printers, etc.

The computer **1102** can operate in a networked environment using logical connections via wired and/or wireless communications to one or more remote computers, such as a remote computer(s) **1148**. The remote computer(s) **1148** can be a workstation, a server computer, a router, a personal computer, portable computer, microprocessor-based entertainment appliance, a peer device or other common network node, and typically comprises many or all of the elements described relative to the computer **1102**, although, for purposes of brevity, only a memory/storage device **1150** is illustrated. The logical connections depicted comprise wired/wireless connectivity to a local area network (LAN) **1152** and/or larger networks, e.g., a wide area network (WAN) **1154**. Such LAN and WAN networking environments are commonplace in offices and companies, and facilitate enterprise-wide computer networks, such as intranets, all of which can connect to a global communications network, e.g., the Internet.

When used in a LAN networking environment, the computer **1102** can be connected to the local network **1152** through a wired and/or wireless communication network interface or adapter **1156**. The adapter **1156** can facilitate wired or wireless communication to the LAN **1152**, which can also comprise a wireless AP disposed thereon for communicating with the wireless adapter **1156**.

When used in a WAN networking environment, the computer **1102** can comprise a modem **1158** or can be connected to a communications server on the WAN **1154** or has other means for establishing communications over the WAN **1154**, such as by way of the Internet. The modem **1158**, which can be internal or external and a wired or wireless device, can be connected to the system bus **1108** via the input device interface **1142**. In a networked environment, program modules depicted relative to the computer **1102** or portions thereof, can be stored in the remote memory/storage device **1150**. It will be appreciated that the network connections shown are example and other means of establishing a communications link between the computers can be used.

The computer **1102** can be operable to communicate with any wireless devices or entities operatively disposed in wireless communication, e.g., a printer, scanner, desktop and/or portable computer, portable data assistant, communications satellite, any piece of equipment or location associated with a wirelessly detectable tag (e.g., a kiosk, news stand, restroom), and telephone. This can comprise Wireless Fidelity (Wi-Fi)

and BLUETOOTH® wireless technologies. Thus, the communication can be a predefined structure as with a conventional network or simply an ad hoc communication between at least two devices.

Wi-Fi can allow connection to the Internet from a couch at home, a bed in a hotel room or a conference room at work, without wires. Wi-Fi is a wireless technology similar to that used in a cell phone that enables such devices, e.g., computers, to send and receive data indoors and out; anywhere within the range of a base station. Wi-Fi networks use radio technologies called IEEE 802.11 (a, b, g, n, ac, etc.) to provide secure, reliable, fast wireless connectivity. A Wi-Fi network can be used to connect computers to each other, to the Internet, and to wired networks (which can use IEEE 802.3 or Ethernet). Wi-Fi networks operate in the unlicensed 2.4 and 5 GHz radio bands for example or with products that contain both bands (dual band), so the networks can provide real-world performance similar to the basic 10BaseT wired Ethernet networks used in many offices.

FIG. **12** presents an example embodiment **1200** of a mobile network platform **1210** that can implement and exploit one or more aspects of the disclosed subject matter described herein. In one or more embodiments, the mobile network platform **1210** can generate and receive signals transmitted and received by base stations (e.g., base station devices **104** and **508**) and repeater devices (e.g., repeater devices **710**, **806**, and **900**) associated with the disclosed subject matter. Generally, wireless network platform **1210** can comprise components, e.g., nodes, gateways, interfaces, servers, or disparate platforms, that facilitate both packet-switched (PS) (e.g., internet protocol (IP), frame relay, asynchronous transfer mode (ATM)) and circuit-switched (CS) traffic (e.g., voice and data), as well as control generation for networked wireless telecommunication. As a non-limiting example, wireless network platform **1210** can be included in telecommunications carrier networks, and can be considered carrier-side components as discussed elsewhere herein. Mobile network platform **1210** comprises CS gateway node(s) **1212** which can interface CS traffic received from legacy networks like telephony network(s) **1240** (e.g., public switched telephone network (PSTN), or public land mobile network (PLMN)) or a signaling system #7 (SS7) network **1260**. Circuit switched gateway node(s) **1212** can authorize and authenticate traffic (e.g., voice) arising from such networks. Additionally, CS gateway node(s) **1212** can access mobility, or roaming, data generated through SS7 network **1260**; for instance, mobility data stored in a visited location register (VLR), which can reside in memory **1230**. Moreover, CS gateway node(s) **1212** interfaces CS-based traffic and signaling and PS gateway node(s) **1218**. As an example, in a 3GPP UMTS network, CS gateway node(s) **1212** can be realized at least in part in gateway GPRS support node(s) (GGSN). It should be appreciated that functionality and specific operation of CS gateway node(s) **1212**, PS gateway node(s) **1218**, and serving node(s) **1216**, is provided and dictated by radio technology(ies) utilized by mobile network platform **1210** for telecommunication.

In addition to receiving and processing CS-switched traffic and signaling, PS gateway node(s) **1218** can authorize and authenticate PS-based data sessions with served mobile devices. Data sessions can comprise traffic, or content(s), exchanged with networks external to the wireless network platform **1210**, like wide area network(s) (WANs) **1250**, enterprise network(s) **1270**, and service network(s) **1280**, which can be embodied in local area network(s) (LANs), can also be interfaced with mobile network platform **1210** through PS gateway node(s) **1218**. It is to be noted that WANs **1250** and enterprise network(s) **1270** can embody, at least in part, a service network(s) like IP multimedia subsystem (IMS). Based on radio technology layer(s) available in technology resource(s), packet-switched gateway node(s) **1218** can generate packet data protocol contexts when a data session is established; other data structures that facilitate routing of packetized data also can be generated. To that end, in an aspect, PS gateway node(s) **1218** can comprise a tunnel interface (e.g., tunnel termination gateway (TTG) in 3GPP UMTS network(s) (not shown)) which can facilitate packetized communication with disparate wireless network(s), such as Wi-Fi networks.

In embodiment **1200**, wireless network platform **1210** also comprises serving node(s) **1216** that, based upon available radio technology layer(s) within technology resource(s), convey the various packetized flows of data streams received through PS gateway node(s) **1218**. It is to be noted that for technology resource(s) that rely primarily on CS communication, server node(s) can deliver traffic without reliance on PS gateway node(s) **1218**; for example, server node(s) can embody at least in part a mobile switching center. As an example, in a 3GPP UMTS network, serving node(s) **1216** can be embodied in serving GPRS support node(s) (SGSN).

For radio technologies that exploit packetized communication, server(s) **1214** in wireless network platform **1210** can execute numerous applications that can generate multiple disparate packetized data streams or flows, and manage (e.g., schedule, queue, format . . .) such flows. Such application(s) can comprise add-on features to standard services (for example, provisioning, billing, customer support . . .) provided by wireless network platform **1210**. Data streams (e.g., content(s) that are part of a voice call or data session) can be conveyed to PS gateway node(s) **1218** for authorization/authentication and initiation of a data session, and to serving node(s) **1216** for communication thereafter. In addition to application server, server(s) **1214** can comprise utility server(s), a utility server can comprise a provisioning server, an operations and maintenance server, a security server that can implement at least in part a certificate authority and firewalls as well as other security mechanisms, and the like. In an aspect, security server(s) secure communication served through wireless network platform **1210** to ensure network's operation and data integrity in addition to authorization and authentication procedures that CS gateway node(s) **1212** and PS gateway node(s) **1218** can enact. Moreover, provisioning server(s) can provision services from external network(s) like networks operated by a disparate service provider; for instance, WAN **1250** or Global Positioning System (GPS) network(s) (not shown). Provisioning server(s) can also provision coverage through networks associated to wireless network platform **1210** (e.g., deployed and operated by the same service provider), such as the distributed antennas networks shown in FIG. **1**(*s*) that enhance wireless service coverage by providing more network coverage. Repeater devices such as those shown in FIGS. **7**, **8**, and **9** also improve network coverage in order to enhance subscriber service experience by way of UE **1275**.

It is to be noted that server(s) **1214** can comprise one or more processors configured to confer at least in part the functionality of macro network platform **1210**. To that end, the one or more processor can execute code instructions stored in memory **1230**, for example. It is should be appreciated that server(s) **1214** can comprise a content manager, which operates in substantially the same manner as described hereinbefore.

In example embodiment **1200**, memory **1230** can store information related to operation of wireless network platform **1210**. Other operational information can comprise provision-

ing information of mobile devices served through wireless platform network **1210**, subscriber databases; application intelligence, pricing schemes, e.g., promotional rates, flat-rate programs, couponing campaigns; technical specification(s) consistent with telecommunication protocols for operation of disparate radio, or wireless, technology layers; and so forth. Memory **1230** can also store information from at least one of telephony network(s) **1240**, WAN **1250**, enterprise network(s) **1270**, or SS7 network **1260**. In an aspect, memory **1230** can be, for example, accessed as part of a data store component or as a remotely connected memory store.

In order to provide a context for the various aspects of the disclosed subject matter, FIG. **12**, and the following discussion, are intended to provide a brief, general description of a suitable environment in which the various aspects of the disclosed subject matter can be implemented. While the subject matter has been described above in the general context of computer-executable instructions of a computer program that runs on a computer and/or computers, those skilled in the art will recognize that the disclosed subject matter also can be implemented in combination with other program modules. Generally, program modules comprise routines, programs, components, data structures, etc. that perform particular tasks and/or implement particular abstract data types.

Turning now to FIGS. **13***a*, **13***b*, and **13***c*, illustrated are block diagrams of example, non-limiting embodiments of a slotted waveguide coupler system **1300** in accordance with various aspects described herein. In particular, cross sections of various waveguides are presented near the junction where the waveguide launches a guided wave along a wire. In FIG. **13***a*, the waveguide coupler system comprises a wire **1306** that is positioned with respect to a waveguide **1302**, such that the wire **1306** fits within or near a slot formed in the waveguide **1302** that runs longitudinally with respect to the wire **1306**. The opposing ends **1304***a* and **1304***b* of the waveguide **1302**, and the waveguide **1302** itself, surrounds less than 180 degrees of the wire surface of the wire **1306**.

In FIG. **13***b* the waveguide coupler system comprises a wire **1314** that is positioned with respect to a waveguide **1308**, such that the wire **1314** fits within or near a slot formed in the waveguide **1308** that runs longitudinally with respect to the wire **1314**. The slot surfaces of the waveguide **1308** can be non-parallel, and two different exemplary embodiments are shown in FIG. **13***b*. In the first, slot surfaces **1310***a* and **1310***b* can be non-parallel and aim outwards, slightly wider than the width of the wire **1314**. In the other embodiment, the slots surfaces **1312***a* and **1312***b* can still be non-parallel, but narrow to form a slot opening smaller than a width of the wire **1314**. Any range of angles of the non-parallel slot surfaces are possible, of which these are two exemplary embodiments.

In FIG. **13***c*, the waveguide coupler system shows a wire **1320** that fits within a slot formed in waveguide **1316**. The slot surfaces **1318***a* and **1318***b* in this exemplary embodiment can be parallel, but the axis **1326** of the wire **1320** is not aligned with the axis **1324** of the waveguide **1316**. The waveguide **1316** and the wire **1320** are therefore not coaxially aligned. In another embodiment, shown, a possible position of the wire at **1322** also has an axis **1328** that is not aligned with the axis **1324** of the waveguide **1316**.

It is to be appreciated that while three different embodiments showing a) waveguide surfaces that surround less than 180 degrees of the wire, b) non parallel slot surfaces, and c) coaxially unaligned wires and waveguide were shown separately in FIGS. **13***a*, **13***b*, and **13***c*, in various embodiments, diverse combinations of the listed features are possible.

Turning now to FIG. **14**, illustrated is an example, non-limiting embodiment of a waveguide coupling system **1400** in accordance with various aspects described herein. FIG. **14** depicts a cross sectional representation of the waveguide and wire embodiments shown in FIGS. **2**, **3**, **4**, etc. As can be seen in **1400**, the wire **1404** can be positioned directly next to and touching waveguide **1402**. In other embodiments, as shown in waveguide coupling system **1410** in FIG. **14***b*, the wire **1414** can still be placed near, but not actually touching waveguide strip **1412**. In both cases, electromagnetic waves traveling along the waveguides can induce other electromagnetic waves on to the wires and vice versa. Also, in both embodiments, the wires **1404** and **1414** are placed outside the cross-sectional area defined by the outer surfaces of waveguides **1402** and **1412**.

For the purposes of this disclosure, a waveguide does not surround, in substantial part, a wire surface of a wire when the waveguide does not surround an axial region of the surface, when viewed in cross-section, of more than 180 degrees. For avoidance of doubt, a waveguide does not surround, in substantial part a surface of a wire when the waveguide surrounds an axial region of the surface, when viewed in cross-section, of 180 degrees or less.

It is to be appreciated that while FIGS. **14** and **14***b* show wires **1404** and **1414** having a circular shape and waveguides **1402** and **1412** having rectangular shapes, this is not meant to be limiting. In other embodiments, wires and waveguides can have a variety of shapes, sizes, and configurations. The shapes can include, but not be limited to: ovals or other ellipsoid shapes, octagons, quadrilaterals or other polygons with either sharp or rounded edges, or other shapes. Additionally, in some embodiments, the wires **1404** and **1414** can be stranded wires comprising smaller gauge wires, such as a helical strand, braid or other coupling of individual strands into a single wire. Any of wires and waveguides shown in the figures and described throughout this disclosure can include one or more of these embodiments.

In the subject specification, terms such as "store," "storage," "data store," data storage," "database," and substantially any other information storage component relevant to operation and functionality of a component, refer to "memory components," or entities embodied in a "memory" or components comprising the memory. It will be appreciated that the memory components described herein can be either volatile memory or nonvolatile memory, or can comprise both volatile and nonvolatile memory, by way of illustration, and not limitation, volatile memory, non-volatile memory, disk storage, and memory storage. Further, nonvolatile memory can be included in read only memory (ROM), programmable ROM (PROM), electrically programmable ROM (EPROM), electrically erasable ROM (EEPROM), or flash memory. Volatile memory can comprise random access memory (RAM), which acts as external cache memory. By way of illustration and not limitation, RAM is available in many forms such as synchronous RAM (SRAM), dynamic RAM (DRAM), synchronous DRAM (SDRAM), double data rate SDRAM (DDR SDRAM), enhanced SDRAM (ESDRAM), Synchlink DRAM (SLDRAM), and direct Rambus RAM (DRRAM). Additionally, the disclosed memory components of systems or methods herein are intended to comprise, without being limited to comprising, these and any other suitable types of memory.

Moreover, it will be noted that the disclosed subject matter can be practiced with other computer system configurations, comprising single-processor or multiprocessor computer systems, mini-computing devices, mainframe computers, as well as personal computers, hand-held computing devices (e.g., PDA, phone, watch, tablet computers, netbook computers, etc.), microprocessor-based or programmable consumer

or industrial electronics, and the like. The illustrated aspects can also be practiced in distributed computing environments where tasks are performed by remote processing devices that are linked through a communications network; however, some if not all aspects of the subject disclosure can be practiced on stand-alone computers. In a distributed computing environment, program modules can be located in both local and remote memory storage devices.

Some of the embodiments described herein can also employ artificial intelligence (AI) to facilitate automating one or more features described herein. For example, artificial intelligence can be used to determine positions around a wire that dielectric waveguides **604** and **606** should be placed in order to maximize transfer efficiency. The embodiments (e.g., in connection with automatically identifying acquired cell sites that provide a maximum value/benefit after addition to an existing communication network) can employ various AI-based schemes for carrying out various embodiments thereof. Moreover, the classifier can be employed to determine a ranking or priority of the each cell site of the acquired network. A classifier is a function that maps an input attribute vector, x=(x1, x2, x3, x4, . . . , xn), to a confidence that the input belongs to a class, that is, f(x)=confidence(class). Such classification can employ a probabilistic and/or statistical-based analysis (e.g., factoring into the analysis utilities and costs) to prognose or infer an action that a user desires to be automatically performed. A support vector machine (SVM) is an example of a classifier that can be employed. The SVM operates by finding a hypersurface in the space of possible inputs, which the hypersurface attempts to split the triggering criteria from the non-triggering events. Intuitively, this makes the classification correct for testing data that is near, but not identical to training data. Other directed and undirected model classification approaches comprise, e.g., naïve Bayes, Bayesian networks, decision trees, neural networks, fuzzy logic models, and probabilistic classification models providing different patterns of independence that can be employed. Classification as used herein also is inclusive of statistical regression that is utilized to develop models of priority.

As will be readily appreciated, one or more of the embodiments can employ classifiers that are explicitly trained (e.g., via a generic training data) as well as implicitly trained (e.g., via observing UE behavior, operator preferences, historical information, receiving extrinsic information). For example, SVMs can be configured via a learning or training phase within a classifier constructor and feature selection module. Thus, the classifier(s) can be used to automatically learn and perform a number of functions, including but not limited to determining according to a predetermined criteria which of the acquired cell sites will benefit a maximum number of subscribers and/or which of the acquired cell sites will add minimum value to the existing communication network coverage, etc.

As used in some contexts in this application, in some embodiments, the terms "component", "system" and the like are intended to refer to, or comprise, a computer-related entity or an entity related to an operational apparatus with one or more specific functionalities, wherein the entity can be either hardware, a combination of hardware and software, software, or software in execution. As an example, a component may be, but is not limited to being, a process running on a processor, a processor, an object, an executable, a thread of execution, computer-executable instructions, a program, and/or a computer. By way of illustration and not limitation, both an application running on a server and the server can be a component. One or more components may reside within a process and/or thread of execution and a component may be localized on one computer and/or distributed between two or more computers. In addition, these components can execute from various computer readable media having various data structures stored thereon. The components may communicate via local and/or remote processes such as in accordance with a signal having one or more data packets (e.g., data from one component interacting with another component in a local system, distributed system, and/or across a network such as the Internet with other systems via the signal). As another example, a component can be an apparatus with specific functionality provided by mechanical parts operated by electric or electronic circuitry, which is operated by a software or firmware application executed by a processor, wherein the processor can be internal or external to the apparatus and executes at least a part of the software or firmware application. As yet another example, a component can be an apparatus that provides specific functionality through electronic components without mechanical parts, the electronic components can comprise a processor therein to execute software or firmware that confers at least in part the functionality of the electronic components. While various components have been illustrated as separate components, it will be appreciated that multiple components can be implemented as a single component, or a single component can be implemented as multiple components, without departing from example embodiments.

Further, the various embodiments can be implemented as a method, apparatus or article of manufacture using standard programming and/or engineering techniques to produce software, firmware, hardware or any combination thereof to control a computer to implement the disclosed subject matter. The term "article of manufacture" as used herein is intended to encompass a computer program accessible from any computer-readable device or computer-readable storage/communications media. For example, computer readable storage media can include, but are not limited to, magnetic storage devices (e.g., hard disk, floppy disk, magnetic strips), optical disks (e.g., compact disk (CD), digital versatile disk (DVD)), smart cards, and flash memory devices (e.g., card, stick, key drive). Of course, those skilled in the art will recognize many modifications can be made to this configuration without departing from the scope or spirit of the various embodiments.

In addition, the words "example" and "exemplary" are used herein to mean serving as an instance or illustration. Any embodiment or design described herein as "example" or "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments or designs. Rather, use of the word example or exemplary is intended to present concepts in a concrete fashion. As used in this application, the term "or" is intended to mean an inclusive "or" rather than an exclusive "or". That is, unless specified otherwise or clear from context, "X employs A or B" is intended to mean any of the natural inclusive permutations. That is, if X employs A; X employs B; or X employs both A and B, then "X employs A or B" is satisfied under any of the foregoing instances. In addition, the articles "a" and "an" as used in this application and the appended claims should generally be construed to mean "one or more" unless specified otherwise or clear from context to be directed to a singular form.

Moreover, terms such as "user equipment," "mobile station," "mobile," subscriber station," "access terminal," "terminal," "handset," "mobile device" (and/or terms representing similar terminology) can refer to a wireless device utilized by a subscriber or user of a wireless communication service to receive or convey data, control, voice, video, sound, gaming or substantially any data-stream or signaling-stream. The

foregoing terms are utilized interchangeably herein and with reference to the related drawings.

Furthermore, the terms "user," "subscriber," "customer," "consumer" and the like are employed interchangeably throughout, unless context warrants particular distinctions among the terms. It should be appreciated that such terms can refer to human entities or automated components supported through artificial intelligence (e.g., a capacity to make inference based, at least, on complex mathematical formalisms), which can provide simulated vision, sound recognition and so forth.

As employed herein, the term "processor" can refer to substantially any computing processing unit or device comprising, but not limited to comprising, single-core processors; single-processors with software multithread execution capability; multi-core processors; multi-core processors with software multithread execution capability; multi-core processors with hardware multithread technology; parallel platforms; and parallel platforms with distributed shared memory. Additionally, a processor can refer to an integrated circuit, an application specific integrated circuit (ASIC), a digital signal processor (DSP), a field programmable gate array (FPGA), a programmable logic controller (PLC), a complex programmable logic device (CPLD), a discrete gate or transistor logic, discrete hardware components or any combination thereof designed to perform the functions described herein. Processors can exploit nano-scale architectures such as, but not limited to, molecular and quantum-dot based transistors, switches and gates, in order to optimize space usage or enhance performance of user equipment. A processor can also be implemented as a combination of computing processing units.

Turning now to FIG. **15**, a block diagram is shown illustrating an example, non-limiting embodiment of a guided wave communication system **1550**. In operation, a transmission device **1500** receives one or more communication signals **1510** from a communication network or other communications device that include data and generates guided waves **1520** to convey the data via the transmission medium **1525** to the transmission device **1502**. The transmission device **1502** receives the guided waves **1520** and converts them to communication signals **1512** that include the data for transmission to a communications network or other communications device. The communication network or networks can include a wireless communication network such as a cellular voice and data network, a wireless local area network, a satellite communications network, a personal area network or other wireless network. The communication network or networks can include a wired communication network such as a telephone network, an Ethernet network, a local area network, a wide area network such as the Internet, a broadband access network, a cable network, a fiber optic network, or other wired network. The communication devices can include a network edge device, bridge device or home gateway, a set-top box, broadband modem, telephone adapter, access point, base station, or other fixed communication device, a mobile communication device such as an automotive gateway, laptop computer, tablet, smartphone, cellular telephone, or other communication device.

In an example embodiment, the guided wave communication system **1550** can operate in a bi-directional fashion where transmission device **1500** receives one or more communication signals **1512** from a communication network or device that includes other data and generates guided waves **1522** to convey the other data via the transmission medium **1525** to the transmission device **1500**. In this mode of operation, the transmission device **1502** receives the guided waves **1522** and converts them to communication signals **1510** that include the other data for transmission to a communications network or device.

The transmission medium **1525** can include a wire or other conductor or inner portion having at least one inner portion surrounded by a dielectric material, the dielectric material having an outer surface and a corresponding circumference. In an example embodiment, the transmission medium **1525** operates as a single-wire transmission line to guide the transmission of an electromagnetic wave. When the transmission medium **1525** is implemented as a single wire transmission system, it can include a wire. The wire can be insulated or uninsulated, and single-stranded or multi-stranded. In other embodiments, the transmission medium **1525** can contain conductors of other shapes or configurations including wire bundles, cables, rods, rails, pipes. In addition, the transmission medium **1525** can include non-conductors such as dielectric pipes, rods, rails, or other dielectric members; combinations of conductors and dielectric materials or other guided wave transmission medium. It should be noted that the transmission medium **1525** can otherwise include any of the transmission media previously discussed in conjunction with FIGS. **1-14**.

According to an example embodiment, the guided waves **1520** and **1522** can be contrasted with radio transmissions over free space/air or conventional propagation of electrical power or signals through the conductor of a wire. In particular, guided waves **1520** and **1522** are surface waves and other electromagnetic waves that surround all or part of the surface of the transmission medium and propagate with low loss along the transmission medium from transmission device **1500** to transmission device **1502**, and vice versa. The guided waves **1520** and **1522** can have a field structure (e.g., an electromagnetic field structure) that lies primarily or substantially outside of the transmission medium **1525**. In addition to the propagation of guided waves **1520** and **1522**, the transmission medium **1525** may optionally contain one or more wires that propagate electrical power or other communication signals in a conventional manner as a part of one or more electrical circuits.

Turning now to FIG. **16**, a block diagram is shown illustrating an example, non-limiting embodiment of a transmission device **1500** or **1502**. The transmission device **1500** or **1502** includes a communications interface (I/F) **1600**, a transceiver **1610** and a coupler **1620**.

In an example of operation, the communications interface receives a communication signal **1510** or **1512** that includes first data. In various embodiments, the communications interface **1600** can include a wireless interface for receiving a wireless communication signal in accordance with a wireless standard protocol such as LTE or other cellular voice and data protocol, an 802.11 protocol, WIMAX protocol, UltraWideband protocol, Bluetooth protocol, Zigbee protocol, a direct broadcast satellite (DBS) or other satellite communication protocol or other wireless protocol. In addition or in the alternative, the communications interface **1600** includes a wired interface that operates in accordance with an Ethernet protocol, universal serial bus (USB) protocol, a data over cable service interface specification (DOCSIS) protocol, a digital subscriber line (DSL) protocol, a Firewire (IEEE 1394) protocol, or other wired protocol. In additional to standards-based protocols, the communications interface **1600** can operate in conjunction with other wired or wireless protocol. In addition, the communications interface **1600** can optionally operate in conjunction with a protocol stack that includes multiple protocol layers.

In an example of operation, the transceiver **1610** generates a first electromagnetic wave based on the communication signal **1510** or **1512** to convey the first data. The first electromagnetic wave has at least one carrier frequency and at least one corresponding wavelength. In various embodiments, the transceiver **1610** is a microwave transceiver that operates at a carrier frequency with a corresponding wavelength that is less than the circumference of the transmission medium **1525**. The carrier frequency can be within a millimeter wave frequency band of 30 GHz-300 GHz. In one mode of operation, the transceiver **1610** merely upconverts the communications signal or signals **1510** or **1512** for transmission of the first electromagnetic signal in the millimeter wave band. In another mode of operation, the communications interface **1600** either converts the communication signal **1510** or **1512** to a baseband or near baseband signal or extracts the first data from the communication signal **1510** or **1512** and the transceiver **1610** modulates the first data, the baseband or near baseband signal for transmission.

In an example of operation, the coupler **1620** couples the first electromagnetic wave to the transmission medium **1525**. The coupler **1620** can be implemented via a dielectric waveguide coupler or any of the couplers and coupling devices described in conjunction with FIGS. **1-14**. In an example embodiment, the transmission medium **1525** includes a wire or other inner element surrounded by a dielectric material having an outer surface. The dielectric material can include an insulating jacket, a dielectric coating or other dielectric on the outer surface of the transmission medium **1525**. The inner portion can include a dielectric or other insulator, a conductor, air or other gas or void, or one or more conductors.

In an example of operation, the coupling of the first electromagnetic wave to the transmission medium **1525** forms a second electromagnetic wave that is guided to propagate along the outer surface of the dielectric material of the transmission medium via at least one guided wave mode that includes an asymmetric mode and optionally one or more other modes including a fundamental (symmetric) mode or other asymmetric (non-fundamental) mode. The outer surface of the dielectric material can be the outer surface of an insulating jacket, dielectric coating, or other dielectric. In an example embodiment, the first electromagnetic wave generated by the transceiver **1610** is guided to propagate along the coupler via at least one guided wave mode that includes a symmetric mode and wherein a junction between the coupler and the transmission medium induces the asymmetric mode of the second electromagnetic wave and optionally a symmetric mode of the second electromagnetic wave.

In an example embodiment, the transmission medium **1525** is a single wire transmission medium having an outer surface and a corresponding circumference and the coupler **1620** couples the first electromagnetic wave to the single wire transmission medium. In particular, the coupling of the first electromagnetic wave to the single wire transmission medium forms a second electromagnetic wave that is guided to propagate along the outer surface of the single wire transmission medium via at least one guided wave mode that includes at least one asymmetric mode and optionally a symmetric mode and other asymmetric modes, wherein the at least one carrier frequency in within a millimeter wave frequency band and wherein the at least one corresponding wavelength is less than the circumference of the single wire transmission medium. In one mode of operation, the first electromagnetic wave is guided to propagate along the coupler via at least one guided wave mode that includes a symmetric mode and a junction between the coupler and the transmission medium induces both the asymmetric mode of the second electromagnetic wave and, when present, the symmetric mode of the second electromagnetic wave.

While the prior description has focused on the operation of the transceiver **1610** as a transmitter, the transceiver **1610** can also operate to receive electromagnetic waves that convey second data from the single wire transmission medium via the coupler **1620** and to generated communications signals **1510** or **1512**, via communications interface **1600** that includes the second data. Consider embodiments where a third electromagnetic wave conveys second data that also propagates along the outer surface of the dielectric material of the transmission medium **1525**. The coupler **1620** also couples the third electromagnetic wave from the transmission medium **1525** to form a fourth electromagnetic wave. The transceiver **1610** receives the fourth electromagnetic wave and generates a second communication signal that includes the second data. The communication interface **1600** sends the second communication signal to a communication network or a communications device.

Turning now to FIG. **17**, a diagram is shown illustrating an example, non-limiting embodiment of an electromagnetic field distribution. In this embodiment, a transmission medium **1525** in air includes an inner conductor **1700** and an insulating jacket **1702** of dielectric material, is shown in cross section. The diagram includes different gray-scales that represent differing electromagnetic field strengths generated by the propagation of the guided wave having an asymmetric mode. The guided wave has a field structure that lies primarily or substantially outside of the transmission medium **1525** that serves to guide the wave. The regions inside the conductor **1700** have little or no field. Likewise regions inside the insulating jacket **1702** have low field strength. The majority of the electromagnetic field strength is distributed in the lobes **1704** at the outer surface of the insulating jacket **1702** and in close proximity thereof. The presence of an asymmetric guided wave mode is shown by the high electromagnetic field strengths at the top and bottom of the outer surface of the insulating jacket **1702**—as opposed very small field strengths on the other sides of the insulating jacket **1702**.

The example shown corresponds to a 38 GHz wave guided by a wire with a diameter of 1.1 cm and a dielectric insulation of thickness of 0.36 cm. Because the electromagnetic wave is guided by the transmission medium **1525** and the majority of the field strength is concentrated in the air outside of the insulating jacket **1702**, the guided wave can propagate longitudinally down the transmission medium **1525** with very low loss.

In an example embodiment, this particular asymmetric mode of propagation is induced on the transmission medium **1525** by an electromagnetic wave having a frequency that falls within a limited range (such as +25%) of the lower cut-off frequency of the asymmetric mode. This cutoff frequency can vary based on the dimensions and properties of the insulating jacket **1702** and the inner conductor **1700** and can be determined experimentally to have a desired mode pattern. At frequencies lower than the lower cut-off frequency, the asymmetric mode is difficult to induce in the transmission medium **1525** and fails to propagate for all but trivial distances. As the frequency increases above the limited range of frequencies about the cut-off frequency, the asymmetric mode shifts more and more inward of the insulating jacket **1702**. At frequencies much larger than the cut-off frequency, the field strength is no longer concentrated outside of the insulating jacket, but primarily inside of the insulating jacket **1702**. While the transmission medium **1525** provides strong guidance to the electromagnetic wave and propagation

is still possible, ranges are more limited by increased losses due to propagation within the insulating jacket **1702**—as opposed to the surrounding air.

Turning now to FIG. **18**, a diagram is shown illustrating an example, non-limiting embodiment of an electromagnetic field distribution. In particular, a diagram similar to FIG. **17** is shown with common reference numerals used to refer to similar elements.

The example shown corresponds to a 60 GHz wave guided by a wire with a diameter of 1.1 cm and a dielectric insulation of thickness of 0.36 cm. Because the frequency of the wave is above the limited range of the cut-off frequency, the asymmetric mode has shifted inward of the insulating jacket **1702**. In particular, the field strength is concentrated primarily inside of the insulating jacket **1702**. While the transmission medium **1525** provides strong guidance to the electromagnetic wave and propagation is still possible, ranges are more limited when compared with the embodiment of FIG. **17**, by increased losses due to propagation within the insulating jacket **1702**.

Turning now to FIG. **19**, a block diagram is shown illustrating an example, non-limiting embodiment of a transmission device. In particular, a diagram similar to FIG. **16** is presented with common reference numerals used to refer to similar elements. The transmission device **1500** or **1502** includes a communications interface **1600** that receives a communication signal **1510** or **1512** that includes data. The transceiver **1610** generates a first electromagnetic wave based on the communication signal **1510** or **1512** to convey the first data, the first electromagnetic wave having at least one carrier frequency. A coupler **1620** couples the first electromagnetic wave to the transmission medium **1525** having at least one inner portion surrounded by a dielectric material, the dielectric material having an outer surface and a corresponding circumference. The first electromagnetic wave is coupled to the transmission medium to form a second electromagnetic wave that is guided to propagate along the outer surface of the dielectric material via at least one guided wave mode. The at least one guided wave mode includes an asymmetric mode having a lower cutoff frequency and the at least one carrier frequency is selected to be within a limited range of the lower cutoff frequency.

The transmission device **1500** or **1502** includes an optional training controller **1900**. In an example embodiment, the training controller **1900** is implemented by a standalone processor or a processor that is shared with one or more other components of the transmission device **1500** or **1502**. The training controller **1900** selects the at least one carrier frequency to be within the limited range of the lower cutoff frequency based on feedback data received by the transceiver **1610** from at least one remote transmission device coupled to receive the second electromagnetic wave.

In an example embodiment, a third electromagnetic wave transmitted by a remote transmission device **1500** or **1502** conveys second data that also propagates along the outer surface of the dielectric material of a transmission medium **1525**. The second data can be generated to include the feedback data. In operation, the coupler **1620** also couples the third electromagnetic wave from the transmission medium **1525** to form a fourth electromagnetic wave and the transceiver receives the fourth electromagnetic wave and processes the fourth electromagnetic wave to extract the second data.

In an example embodiment, the training controller **1900** operates based on the feedback data to evaluate a plurality of candidate frequencies and to select the at least one carrier frequency to be within the limited range of the lower cutoff frequency, as one of the plurality of candidate frequencies. For example, the candidate frequencies can be selected based on criteria such as: being in a millimeter wave band, having wavelengths greater than an outer circumference of the transmission medium **1525**, being less than the mean collision frequency of electrons in a conductor that makes up a portion of the transmission medium **1525**, based on experimental results that indicate the limited range of frequencies about the cutoff frequency for a particular transmission medium **1525** and a selected asymmetric mode, and/or based on experimental results or simulations.

Consider the following example: a transmission device **1500** begins operation under control of the training controller **1900** by sending a plurality of guided waves containing test data at a corresponding plurality of candidate frequencies to a remote transmission device **1502** coupled to the transmission medium **1525**. The test data indicates the particular candidate frequency of the signal. The training controller **1900** at the remote transmission device **1502** receives the test data from any of the guided waves that were properly received and determines the best candidate frequency, a set of acceptable candidate frequencies, or a rank ordering of candidate frequencies. This candidate frequency or frequencies is generated by the training controller **1900** based on one or more optimizing criteria such as received signal strength, bit error rate, packet error rate, signal to noise ratio or other optimizing criteria can be generated by the transceiver **1610** of the remote transmission device **1502**. The training controller **1900** generates feedback data that indicates the candidate frequency or frequencies and sends the feedback data to the transceiver **1610** for transmission to the transmission device **1500**. The transmission device **1500** and **1502** can then communicate data with one another utilizing the indicated carrier frequency or frequencies.

While the procedure above has been described in a start-up or initialization mode of operation, each transmission device **1500** or **1502** can send test signals or otherwise evaluate candidate frequencies at other times as well. In an example embodiment, the communication protocol between the transmission devices **1500** and **1502** can include a periodic test mode where either full testing or more limited testing of a subset of candidate frequencies are tested and evaluated. In other modes of operation, the re-entry into such a test mode can be triggered by a degradation of performance due to an impairment, weather conditions, etc. In an example embodiment, the receiver bandwidth of the transceiver **1610** is either sufficiently wide to include all candidate frequencies or can be selectively adjusted by the training controller **1900** to a training mode where the receiver bandwidth of the transceiver **1610** is sufficiently wide to include all candidate frequencies.

While the guided wave above has been described as propagating on the outer surface of an outer dielectric surface of the transmission medium **1525**, other outer surfaces of a transmission medium **1525** including the outer surface of a bare wire could likewise be employed. Further, while the training controller **1900** has been described above as selecting a candidate frequency to be within a limited range of the lower cut-off frequency of an asymmetric mode, the training controller **1900** could be used to establish a candidate frequency that optimizes, substantially optimizes or pareto optimizes the propagation along a transmission medium **1525** based on one or more performance criteria such as throughput, packet error rate, signal strength, signal to noise ratio, signal to noise and interference ratio, channel separation in a multi-channel system, and/or other performance criteria—with or without an asymmetric mode and with or without regard to whether

the candidate frequency falls within a limited range of the lower cutoff frequency of any particular mode.

FIG. **20** is a block diagram of an example, non-limiting embodiment of a transmission device in accordance with various aspects described herein. In particular, a transmission device **2000** is shown that includes a plurality of transceivers **2020**, each having a transmitting device (or transmitter) and/or a receiving device (receiver) that is coupled to a corresponding waveguide **2022** and coupler **2004**. The plurality of couplers **2004** can be referred to collectively as a "coupling module". Each coupler **2004** of such as coupling module includes a receiving portion **2010** that receives an electromagnetic wave **2006** conveying first data from a transmitting device of transceiver **2020** via waveguide **2022**. A guiding portion **2012** of the coupler **2004** guides a first electromagnetic wave **2006** to a junction **2014** for coupling the electromagnetic wave **2006** to a transmission medium **2002**. In the embodiment shown, the junction **2014** includes an air gap, however other configurations are possible both with, and without an air gap. The guiding portion **2012** includes a tapered end **2016** that terminates at the junction **2014**.

Each electromagnetic wave **2006** propagates via at least one first guided wave mode. The coupling of the electromagnetic waves **2006** to the transmission medium **2002** via the junctions **2014** forms a plurality of electromagnetic waves **2008** that are guided to propagate along the outer surface of the transmission medium **2002** via at least one second guided wave mode that differs from the at least one first guided wave mode. The transmission medium **2002** can be a single wire transmission medium or other transmission medium that supports the propagation of the electromagnetic waves **2008** along the outer surface of the transmission medium **2002** to convey the first data.

In various embodiments, the electromagnetic waves **2006** propagate along a coupler **2004** via one or more first guided wave modes that can include either exclusively or substantially exclusively a symmetrical (fundamental) mode, however other modes can optionally be included in addition or in the alternative. In accordance with these embodiments, the at least one second guided wave mode of the electromagnetic waves **2008** includes at least one asymmetric mode that is not included in the guided wave modes of the electromagnetic waves **2006** that propagate along each coupler **2004**. In operation, the junctions **2014** induce the electromagnetic waves **2008** on transmission medium **2002** to optionally include a symmetric mode, but also one or more asymmetric modes not included in the guided wave modes of the electromagnetic wave **2006** that propagate along the coupler **2004**.

More generally, consider the at least one first guided wave mode to be defined by the set of modes S1 where:

$$S1=(m11,m12,m13,\dots)$$

And where the individual modes m11, m12, m13, . . . can each be either a symmetrical mode or an asymmetrical mode that propagate more than a trivial distance, i.e. that propagate along the length of the guiding portion **2012** of a coupler **2004** from the receiving end **2010** to the other end **2016**.

Also consider the at least one second guided wave mode to be defined by the set of modes S2 where:

$$S2=(m21,m22,m23,\dots)$$

And, the individual modes m21, m22, m23, . . . can each be either a symmetrical mode or an asymmetrical mode that propagate along the length of the transmission medium **2002** more than a trivial distance, i.e. that propagate sufficiently to reach a remote transmission device coupled at a different location on the transmission medium **2002**.

In various embodiments, that condition that at least one first guided wave mode is different from at least one second guided wave mode implies that $S1 \neq S2$. In particular, S1 may be a proper subset of S2, S1 may be a proper subset of S2, or the intersection between S1 and S2 may be the null set.

In addition to operating as a transmitter, the transmission device **2000** can operate as a receiver as well. In this mode of operation, a plurality of electromagnetic waves **2018** conveys second data that also propagates along the outer surface of the transmission medium **2002**, but in the opposite direction of the electromagnetic waves **2008**. Each junction **2014** couples one of the electromagnetic waves **2018** from the transmission medium **2002** to form an electromagnetic wave **2016** that is guided to a receiver of the corresponding transceiver **2020** by the guiding portion **2012**.

In various embodiments, the first data conveyed by the plurality of second electromagnetic waves **2008** includes a plurality of data streams that differ from one another and wherein the each of the plurality of first electromagnetic waves **2006** conveys one of the plurality of data streams. More generally, the transceivers **2020** operate to convey either the same data stream or different data streams via time division multiplexing, frequency division multiplexing, or mode division multiplexing. In this fashion, the transceivers **2020** can be used in conjunction with a MIMO transmission system to send and receive full duplex data via azimuthal diversity, cyclic delay diversity, spatial coding, space time block coding, space frequency block coding, hybrid space time/frequency block coding, single stream multi-coupler spatial mapping or other transmission/reception scheme.

While the transmission device **2000** is shown with two transceivers **2020** and two couplers **2004** arranged at the top and bottom of the transmission medium **2002**, other configurations can include three or more transceivers and corresponding couplers. For example, a transmission device **2000** with four transceivers **2020** and four couplers **2004** can be arranged at azimuthally around the outer surface of a cylindrical transmission medium at equidistant orientations of 0, $\pi/2$, π, and $3\pi/4$. Considering a further example, a transmission device **2000** with n transceivers **2020** can include n couplers **2004** arranged azimuthally around the outer surface of a cylindrical transmission medium at angles $2\pi/\pi$ apart.

FIG. **21** is a block diagram of an example, non-limiting embodiment of a transmission device in accordance with various aspects described herein. In particular, a transmission device **2100** is shown that can be implemented as part of a repeater, such as repeater device **710** presented in conjunction with FIG. **7** or other repeater that includes two similar transceivers, **2020** and **2020'**. Similar elements from FIG. **20** are represented by common reference numerals. In addition, the transmission device **2100** includes a shield **2125**. In an embodiment, the shield **2125** is constructed of absorbing material and surrounds the transmission medium **2002**. In operation, when an electromagnetic wave **2104** is coupled to coupler **2004** to generate electromagnetic wave **2108**, a portion continues along transmission medium **2002** as electromagnetic wave **2106**. The shield **2125** substantially or entirely absorbs the electromagnetic wave **2106** so that it will not continue to propagate, mitigating interference with the operation of the transceiver **2020'** on the other side of the shield **2125**. Similarly, when an electromagnetic wave **2110** is coupled to coupler **2004** to generate electromagnetic wave **2114**, a portion continues along transmission medium **2002** as electromagnetic wave **2112**. The shield **2125** substantially or entirely absorbs the electromagnetic wave **2112** so that it will not continue to propagate, mitigating interference with the operation of the transceiver **2020** on the other side of the

shield **2125**. As shown, the shield **2125** is tapered on both sides to minimize reflections and/or to provide impedance matching, however other designs are likewise possible.

FIG. **22** is a diagram illustrating an example, non-limiting embodiment of an electromagnetic distribution in accordance with various aspects described herein. In particular, an electromagnetic distribution **2200** is presented in two dimensions for a transmission device that includes coupler **2202**, such as any of the dielectric waveguide couplers previously described. The coupler **2202** couples an electromagnetic wave for propagation along an outer surface of a transmission medium **2204**, such as a single wire transmission medium.

The coupler **2202** guides the electromagnetic wave to a junction at x_0 via a symmetrical guided wave mode. As shown, the majority of the energy of the electromagnetic wave that propagates along the coupler **2202** is contained within the coupler **2202**. The junction at x_0 couples the electromagnetic wave to a transmission medium at an azimuthal angle corresponding to the bottom of the transmission medium **2204**. This coupling induces an electromagnetic wave that is guided to propagate along the outer surface of the transmission medium via at least one guided wave mode. The majority of the energy of the electromagnetic wave that propagates along the transmission medium **2204** is outside or, but in close proximity to the outer surface of the transmission medium **2204**. In the example shown, the junction at x_0 forms an electromagnetic wave that propagates via both a symmetrical mode and at least one asymmetrical surface mode, such as the first order mode presented in conjunction with FIG. **17**, that skims the surface of the transmission medium **2204**.

The combination of symmetrical and asymmetrical propagation mode(s) of the electromagnetic wave that propagates along the surface of the transmission medium **2204** forms an envelope that varies as a function of angular deviation from the azimuthal angle that defines the orientation of the coupler **2202** to the transmission medium **2204** as well as a function of the longitudinal displacement from the junction at x_0. Consider the electromagnetic wave to be represented by the function $W(\Delta\theta, \Delta x, t)$, where $\Delta\theta$ represents the angular deviation from the azimuthal angle that defines the orientation of the coupler **2202** to the transmission medium **2204**, x represents function of the longitudinal displacement from the junction at x_0, and t represents time. The envelope of the electromagnetic wave W can be represented by $A(\Delta\theta, \Delta x)$, where, for $0 \le t \le \infty$,

$$A(\Delta\theta,\Delta x)=\mathrm{Max}(W(\Delta\theta,\Delta x,t))$$

Therefore, while the electromagnetic wave W varies as a function of time as a wave propagates along the length of the transmission medium, the envelope A is the maximum amplitude of the electromagnetic wave for any time. Like a standing wave, the envelope A is a relatively time-stationary function of the longitudinal displacement along a transmission medium. While the envelope may vary based on slowly changing parameters of the transmission medium such as temperature or other environmental conditions, the envelope generally does not otherwise vary as a function of time. Unlike a standing wave however, the wavelength of the envelope function is not the same as the wavelength of the electromagnetic wave. In particular, the wavelength of the envelope function is much greater than the wavelength of the underlying electromagnetic wave. In the example shown, the wavelength of the underlying electromagnetic wave $\lambda_c \approx 0.8$ cm while the envelope function of the envelope function is more than 10 times greater. Further, unlike a traditional standing wave the envelope A also varies as a function of $\Delta\theta$, the angular deviation from the azimuthal angle that defines the orientation of the coupler **2202** to the transmission medium **2204**.

In the example shown, the coupler **2202** induces an electromagnetic wave on the transmission medium **2204**—at the bottom of the transmission medium **2204**. At the junction at x_0, the electromagnetic wave is concentrated at the bottom of the transmission medium with a much smaller level of radiation on the top of the transmission medium **2004**. The envelope of the electromagnetic wave at the bottom of the transmission medium **2204** decreases along the transmission medium in the direction of propagation **2206**, until it reaches a minimum at x_1. Considering instead, the top of the transmission medium **2204**, the envelope of the electromagnetic wave increases along the transmission medium in the direction of propagation **2206**, until it reaches a maximum at x_1. In this fashion, the envelope roughly follows a serpentine pattern, oscillating between minima and maxima and concentration long the top and bottom of the transmission medium **2204**, as the electromagnetic wave propagates along the direction of propagation **2206**.

The value $\Delta\theta=0$ corresponds to no angular deviation from the azimuthal angle that defines the orientation of the coupler **2202** to the transmission medium **2204**,—i.e., the bottom of the transmission medium **2204**. The opposite surface, at the top of the transmission medium **2204**, corresponds to $\Delta\theta=\pi$, an angular deviation of π radians. In the embodiment shown, for $\Delta\theta=0$ the envelope has local maxima at x_0 and x_2 and a local minimum at x_1. Conversely, for $\Delta\theta=\pi$, the envelope has local minima at x_0 and x_2 and a local maximum at x_1.

FIG. **23** is a diagram illustrating an example, non-limiting embodiment of a function in accordance with various aspects described herein. In particular, the graph **2300** presents approximations of the envelope A for two different fixed angular deviations $\Delta\theta$. As shown, the envelope A is a periodic function that varies between a maximum value and a minimum value A_{min}.

The function **2302** presents an approximation of the envelope A for a fixed angular deviation $\Delta\theta=0$. In this case,

$$A(0,\Delta x)=((A_{max}-A_{min})D(\Delta x)\cos(2\pi\Delta x/\lambda_s))+A_{min}$$

Where $D(\Delta x)$ is a monotonically decreasing function that has a value of

$$D(0)=1$$

that represents the gradual decay in amplitude of the electromagnetic wave W as it propagates along the length of the transmission medium and where λ_s represents the wavelength of the envelope. In the example shown:

$$\lambda_s=2(x_1-x_0)$$

In this example, for $\Delta\theta=0$ the envelope has local maxima at:

$$\Delta x=0,\lambda_s,2\lambda_s$$

Or more generally at,

$$\Delta x=N\lambda_s$$

where N is an integer. Further, for $\Delta\theta=0$ the envelope has local minima at:

$$\Delta x=\lambda_s/2,3\lambda_s/2\ldots$$

Or more generally at,

$$\Delta x=(2N+1)\lambda_s/2$$

The function **2304** presents an approximation of the envelope A for a fixed angular deviation $\Delta\theta=\pi$. In this case,

$$A(\pi,\Delta x)=((A_{max}-A_{min})D(\Delta x)\cos(2\pi\Delta x/\lambda_s+\pi))+A_{min}$$

In this example, for $\Delta\theta=\pi$ the envelope has local minima at:

$$\Delta x=0,\lambda_s,2\lambda_s \ldots$$

Or more generally at,

$$\Delta x=N\lambda_s$$

where N is an integer. Further, for $\Delta\theta=0$ the envelope has local maxima at:

$$\Delta x=\lambda_s/2,3\lambda_s/2 \ldots$$

Or more generally at,

$$\Delta x=(2N+1)\lambda_s/2$$

While the functions **2302** and **2304** present approximations of the envelope A at the top and bottom of the transmission medium, in an embodiment, at least one guided wave mode of the electromagnetic wave W rotates azimuthally as the wave propagates along the length of the transmission medium. In this case, the envelope A can be approximated as follows:

$$A(\Delta\theta,\Delta x)=((A_{max}-A_{min})D(\Delta x)\cos(2\pi\Delta x/\Delta\theta))+A_{min}$$

or

$$A(\Delta\theta,\Delta x)=((A_{max}-A_{min})D(\Delta x)\cos(-2\pi\Delta x/\Delta\theta))+A_{min}$$

Depending on whether the azimuthal rotation is clockwise or counterclockwise.

Note that, in concert with the example presented above, for $\Delta\theta=\pi$ the envelope has local minima at:

$$\Delta x=N\lambda_s$$

And for $\Delta\theta=0$ the envelope has local maxima at:

$$\Delta x=(2N+1)\lambda_s/2$$

Considering fixed values of Δx, for $\Delta x=0$, the envelope has a local minimum at:

$$\Delta\theta=\pi$$

And a local maximum at:

$$\Delta\theta=0$$

For $\Delta x=\lambda_s/2$, the envelope has a local maximum at:

$$\Delta\theta=\pi$$

And a local minimum at:

$$\Delta\theta=0$$

Using the approximations above, the local minima and maxima can be calculated for other azimuthal deviations as well. Considering the case where $\Delta\theta=\pi/2$, and clockwise rotation, the envelope has local maxima at:

$$\Delta x=\lambda_s/4,5\lambda_s/4 \ldots$$

And local minima at:

$$\Delta x=3\lambda_s/4,7\lambda_s/4 \ldots$$

Considering the case where $\Delta\theta=-\pi/2$, and counterclockwise rotation, the envelope has local maxima at:

$$\Delta x=\lambda_s/4,5\lambda_s/4 \ldots$$

And local minima at:

$$\Delta x=3\lambda_s/4,7\lambda_s/4 \ldots$$

Approximations of the envelope A can be useful in designing the placement of multiple couplers in the transmission medium to support simultaneous communications via multiple electromagnetic waves W via azimuthal or spatial diversity. For example, placing one coupler at an azimuthal deviation and/or longitudinal displacement from another coupler that corresponds to a local minimum of the envelope increases the isolation between the electromagnetic waves and reduces the amount of interference between these couplers. Further, placing a receiving coupler at an azimuthal deviation and/or longitudinal displacement from a transmitting coupler at a corresponding local maximum can increase the signal gain and data throughput for an electromagnetic wave that is transmitted from the transmitting coupler to the receiving coupler. Examples of such configurations including various optional functions and features will be explored in conjunction with FIGS. **24-25** that follow.

FIG. **24** is a block diagram of an example, non-limiting embodiment of a transmission system in accordance with various aspects described herein. The transmission system **2400** is presented that includes two transmission devices that are spaced a distance apart along the transmission medium **2002**. In this system the transceiver (Xcvr) **2410** generates an electromagnetic wave **2402** conveying first data. A coupler **2450** guides the electromagnetic wave **2402** to a junction **2412** that couples the electromagnetic wave **2402** to the transmission medium **2002** at a first azimuthal angle to form an electromagnetic wave **2404** that is guided to propagate along the outer surface of the transmission medium **2002** via one or more guided wave modes. The electromagnetic wave **2404** has an envelope that varies as a function of angular deviation $\Delta\theta$ from the first azimuthal angle and the longitudinal displacement Δx from the junction **2412**. The function has a local minimum at an angular deviation $\Delta\theta=\theta_1$ from the first azimuthal angle and an angular displacement $\Delta x=x_1$ from the junction **2412**. The coupler **2454** at junction **2418** forms an electromagnetic wave **2406** from the electromagnetic wave **2404** and guides the electromagnetic wave **2406** to transceiver **2440** to receive the first data.

A remote transceiver **2430** generates an electromagnetic wave **2432** conveying second data that is coupled onto the transmission medium **2002** via coupler **2456** at a junction at **2414** as an electromagnetic wave **2434**. The electromagnetic wave **2434** propagates along the outer surface of the transmission medium **2002** in a direction opposite to the electromagnetic wave **2404**. The coupler **2452** couples the electromagnetic wave **2434** from the transmission medium **2002** at junction **2416** to form an electromagnetic wave **2436** that is guided to the transceiver **2420** that receives the second data. The coupler **2452** at the junction **2416** that corresponds to an angular deviation $\Delta\theta=\theta_1$ from the first azimuthal angle and an angular displacement $\Delta x=x_1$ from the junction **2412**. As shown $\theta_1=\pi$ and $\Delta x=0$, corresponding to a local minimum of the envelope of the electromagnetic wave **2404**. This placement of coupler **2416** helps reduce bleed through of the electromagnetic wave **2404** to the receiver **2420**. A similar effect occurs between transceiver **2430** and transceiver **2440**.

In various embodiments, the couplers of the receiver/transmitter pair **2410**/**2440** are oriented at the same azimuthal orientation and the longitudinal displacement d1 between the junctions **2412** and **2418** is selected so that the receiving coupler **2454** is placed at a local maximum of the envelope. Considering further the examples presented in conjunction with FIG. **23**,

$$d1=N\lambda_s$$

If the electromagnetic wave **2432** is transmitted at the same carrier frequency as the electromagnetic wave **2402**, each electromagnetic wave has the same wavelength and a similar effect occurs between junctions **2414** and **2416**.

Each of the two transmission devices of system **2400** includes a training controller **2425** that operates similar to training controller **1900**. In this embodiment, however, the training controller **2425** selects at least one carrier frequency

of the electromagnetic wave **2402** generated by transceiver **2410** based on feedback data received by the transceiver **2420** via the electromagnetic wave **2436**. The training controller **2435** generates this feedback data based on the reception of the electromagnetic wave **2406** by transceiver **2440** and transmits the feedback data via the electromagnetic wave **2432** generated by transceiver **2430**. The training controllers can operate reciprocally to establish the carrier frequency of the electromagnetic wave **2434**. In the alternative, the training controllers **2425** and **2435** can operate in a cooperative fashion to coordinate the selection of a single carrier frequency that not only promotes propagation of the electromagnetic waves **2404** and **2434** along the transmission medium **2002**, but that further increases the envelope of the desired electromagnetic wave at the receiving coupler while reducing transmitter bleed through for each transmission device.

While each coupler (**2450**, **2452**, **2454** or **2456**) is shown as engaging in unidirectional communication via either a transmitter or receiver of a corresponding transceiver, more generally, each coupler can be coupled to the transceiver for engaging in bidirectional communications in a manner similar to the transmission device described in conjunction with FIG. **20**. In addition, while each transmission device is shown with two transceivers, other designs with one transceiver or three or more transceivers are possible. Further, while each transmission device is shown with two couplers that operate at junctions at the same longitudinal position but at different azimuthal orientation, other configurations with different longitudinal displacements and either the same azimuthal orientation or different azimuthal orientations are likewise possible.

FIG. **25** is a block diagram of an example, non-limiting embodiment of a transmission system in accordance with various aspects described herein. This system **2500** operates in a similar fashion to the transmission system **2400**. The transceiver **2510** and transceiver **2520** are part of one transmission device that communicates with a remote transmission device that includes transceiver **2540** and transceiver **2530**. In operation, transceiver **2510** sends an electromagnetic wave that conveys data to transceiver **2530** and transceiver **2540** sends another electromagnetic wave that conveys data to transceiver **2520**. These two electromagnetic waves traverse the transmission medium **2002** in opposite directions.

The transceiver pair of each transmission device are coupled at opposite azimuthal orientations but at the same spatial displacement. As such, the transceiver **2510** and transceiver **2520** are coupled at the same location, but on opposite sides of the transmission medium **2002**. Likewise, the transceiver **2540** and transceiver **2530** are coupled at the same location, but on opposite sides of the transmission medium **2002**—a distance d2 from the coupling point of the other transmission device.

In this embodiment however, the transceiver pairs that communicate with one another are oriented at different azimuthal deviations. In particular, the couplers of the transceiver pair **2510**/**2530** are oriented at different (opposite) azimuthal orientations and the longitudinal displacement d2 between the junctions is selected so that the receiving coupler is still placed at a local maximum of the envelope. Considering further the examples presented in conjunction with FIG. **23**,

$$d2=N\lambda_s+\lambda_s/2$$

If the transceiver pair **2540**/**2520** employs the same carrier frequency, a similar effect occurs for transmission in the opposite direction along transmission medium.

As shown, each transmission device could include a training controller, such as training controller **2425** to adjust the carrier frequency of the electromagnetic waves so that the placement of each receiving coupler corresponds as closely as possible to a local maximum of the envelope. While each coupler **2004** is shown as engaging in unidirectional communication via either a transmitter or receiver, more generally, each coupler can be coupled to a transceiver that includes both a transmitter and receiver for engaging in bidirectional communications in a manner similar to the transmission device described in conjunction with FIG. **20**.

While FIGS. **24-25** have presented examples where two electromagnetic waves in opposite directions share the same transmission medium, similar configurations that support simultaneous transport of electromagnetic waves in the same direction are likewise possible. Also, while the examples presented in conjunction with FIGS. **24-25** have focused on transmission devices and communication systems with azimuthal deviations of $\Delta\theta=0$ or $\Delta\theta=\pi$, other deviations $\Delta\theta$ are possible. As discussed in conjunction with FIG. **23**, electromagnetic waves may propagate with envelopes having local maxima and minima that support other azimuthal deviations $\Delta\theta$ at corresponding longitudinal displacements Δx. Considering the example where the envelope can be approximated by:

$$A(\Delta\theta,\Delta x)=((A_{max}-A_{min})D(\Delta x)\cos(2\pi\Delta x/\lambda_s+\Delta\theta))+A_{min}$$

and $\Delta\theta=\pi/2$, the envelope has local maxima at:

$$\Delta x=\lambda_s/4,5\lambda_s/4\ldots$$

And local minima at:

$$\Delta x=3\lambda_s/4,7\lambda_s/4\ldots$$

Two transceivers of the same transmission device can be placed with $\Delta\theta=\pi/2$ and $\Delta x=3\lambda_s/4$ and a similar remote transmission device can be placed at a distance of

$$d=(4N+1)\lambda_s/4$$

Other examples with other azimuthal deviations, an optional longitudinal displacement between each transceiver in a transmission device and/or a greater number of transceivers are likewise possible.

FIG. **26** is a block diagram illustrating an example, non-limiting embodiment of a waveguide system **2602** in accordance with various aspects described herein. The waveguide system **2602** can comprise sensors **2604**, a power management system **2605**, a waveguide **2606**, and a communications interface **2608**.

The waveguide system **2602**, can include any of the transmission devices, repeaters, couplers and/or any of the other components previously described in conjunction with FIGS. **1-25**. In particular, the waveguide system **2602** can be coupled to a power line **2610**, or other transmission medium **2002**, for facilitating data communications in accordance with embodiments described in the subject disclosure. The waveguide **2606** can comprise the system **500**, such as shown in FIG. **5**, for inducing electromagnetic waves on a surface of the power line **2610** that longitudinally propagate along the surface of the power line **2610** as described in the subject disclosure. Non-limiting techniques for coupling the waveguide **2606** to the power line **2610** are shown in FIGS. **2-4** and **6**. The waveguide **2606** can also serve as a repeater for retransmitting electromagnetic waves on the same power line **2610** or for routing electromagnetic waves between power lines **2610** as shown in FIGS. **7-8**.

The communications interface **2608** can comprise the communications interface **501** shown in FIG. **5**. The commu-

nications interface **2608** couples to the waveguide **2606** for up-converting signals operating at an original frequency to electromagnetic waves operating at a carrier frequency that propagate on a surface of a coupling device of the waveguide **2606**, such as the dielectric **502** of FIG. **5**, and that induce corresponding electromagnetic waves that propagate on a surface of the power line **2610**. The power line **2610** can be a wire (e.g., single stranded or multi-stranded and braided or bundled together) having a conducting surface or insulated surface. The communications interface **2608** can also receive signals from the waveguide **2606** that have been down-converted from electromagnetic waves operating at a carrier frequency to signals at their original frequency.

Signals received by the communications interface **2608** for up-conversion can include without limitation signals supplied by a base station **2614** over a wired or wireless interface of the communications interface **2608**, wireless signals transmitted by mobile devices **2620** to the base station **2614** for delivery over the wired or wireless interface of the communications interface **2608**, signals supplied by in-building communication devices **2618** over the wired or wireless interface of the communications interface **2608**, and/or wireless signals supplied to the communications interface **2608** by mobile devices **2612** roaming in a wireless communication range of the communications interface **2608**. In embodiments where the waveguide system **2602** functions as a repeater, such as shown in FIGS. **7-8**, the communications interface **2608** may or may not be included in the waveguide system **2602**.

The electromagnetic waves propagating along the surface of the power **2610** can be modulated and formatted to include packets or frames of data that include communication data in a data payload and further can include networking information (such as header information for identifying one or more destination waveguide systems **2602**). The networking information may be provided by the waveguide system **2602** or an originating device such as the base station **2614**, mobile devices **2620**, or in-building devices **2618**, or a combination thereof. Additionally, the modulated electromagnetic waves can include control, synchronization or error correction data for mitigating signal impairments. The networking information and error correction data can be used by a destination waveguide system **2602** for detecting transmissions directed to it, and for down-converting and processing with error correction data transmissions that include voice and/or data signals directed to recipient communication devices communicatively coupled to the destination waveguide system **2602**.

Referring now to the sensors **2604** of the waveguide system **2602**, the sensors **2604** can comprise a temperature sensor **2604***a*, an impairment detection sensor **2604***b*, a loss of energy sensor **2604***c*, a noise sensor **2604***d*, a vibration sensor **2604***e*, an environmental sensor **2604***f*, and an image sensor **2604***g*. The temperature sensor **2604***a* can be used to measure ambient temperature, a temperature of the waveguide **2606**, a temperature of the power line **2610**, or any combination thereof. In one embodiment, temperature metrics can be collected and reported periodically to a network management system **2601** by way of the base station **2614**.

Signal reflections can be caused by obstructions on the power line **2610**. For example, a tree limb shown in FIG. **27**(A) may cause electromagnetic wave reflections when the tree limb is lying on the power line **2610**, or is in close proximity to the power line **2610** which may cause a corona discharge **2702**. Other illustrations of obstructions that can cause electromagnetic wave reflections can include without limitation an object **2706** that has been entangled on the power line **2610** as shown in FIG. **27**(C) (e.g., clothing, a shoe wrapped around a power line **2610** with a shoe string, etc.), a corroded build-up **2712** on the power line **2610** as shown in FIG. **27**(F), or an ice build-up **2714** as shown in FIG. **27**(G). Power grid components may also interfere with the transmission of electromagnetic waves on the surface of power lines **2610**. Illustrations of power grid components that may cause signal reflections include without limitation a transformer **2704** illustrated in FIG. **27**(B) and a joint **2710** for connecting spliced power lines such as illustrated in FIG. **27**(E). A sharp angle **2708** on a power line **2610**, as shown in FIG. **27**(C), may also cause electromagnetic wave reflections.

The impairment detection sensor **2604***b* can comprise a circuit to compare magnitudes of electromagnetic wave reflections to magnitudes of original electromagnetic waves transmitted by the waveguide **2606** to determine how much a downstream impairment in the power line **2610** attenuates transmissions. The impairment detection sensor **2604***b* can further comprise a spectral analyzer circuit for performing spectral analysis on the reflected waves. The spectral data generated by the spectral analyzer circuit can be compared with spectral profiles via pattern recognition, an expert system, curve fitting, matched filtering or other artificial intelligence, classification or comparison technique to identify a type of impairment based on, for example, the spectral profile that most closely matches the spectral data. The spectral profiles can be stored in a memory of the impairment detection sensor **2604***b* or may be remotely accessible by the impairment detection sensor **2604***b*. The profiles can comprise spectral data that models different impairments that may be encountered on power lines **2610** to enable the impairment detection sensor **2604***b* to identify impairments locally. An identification of the impairment if known can be reported to the network management system **2601** by way of the base station **2614**.

In various embodiments, sensors can detect an impairment on the outer surface of the power line **2610** based on transmission of electromagnetic wave test signals. For example, the impairment detection sensor **2604***b* can utilize the waveguide **2606** to transmit electromagnetic waves as test signals to determine a roundtrip time for an electromagnetic wave reflection. The round trip time measured by the impairment detection sensor **2604***b* can be used to calculate a distance traveled by the electromagnetic wave up to a point where the reflection takes place, which enables the impairment detection sensor **2604***b* to calculate a distance from the waveguide **2606** to the downstream impairment on the power line **2610** or other location data that indicates the position of the impairment along the power line **2610**.

The distance calculated can be reported to the network management system **2601** by way of the base station **2614**. In one embodiment, the location of the waveguide system **2602** on the power line **2610** may be known to the network management system **2601**, which the network management system **2601** can use to generate location data that indicates a position of the impairment on the power line **2610** based on a known topology of the power grid. In another embodiment, the waveguide system **2602** can provide its location to the network management system **2601** to assist in the determination of the location of the impairment on the power line **2610**. The location of the waveguide system **2602** can be obtained by the waveguide system **2602** from a pre-programmed location of the waveguide system **2602** stored in a memory of the waveguide system **2602**, or the waveguide system **2602** can determine its location using a GPS receiver (not shown) included in the waveguide system **2602**.

The power management system **2605** provides energy to the aforementioned components of the waveguide system

2602. The power management system 2605 can receive energy from solar cells, or from a transformer (not shown) coupled to the power line 2610, or by inductive coupling to the power line 2610. The power management system 2605 can also include a backup battery and/or a super capacitor or other capacitor circuit for providing the waveguide system 2602 with temporary power. The loss of energy sensor 2604*c* can be used to detect when the waveguide system 2602 has a loss of power condition and/or the occurrence of some other malfunction. For example, the loss of energy sensor 2604*c* can detect when there is a loss of power due to defective solar cells, an obstruction on the solar cells that causes them to malfunction, loss of power on the power line 2610, and/or when the backup power system malfunctions due to expiration of a backup battery, or a detectable defect in a super capacitor. When a malfunction and/or loss of power occurs, the loss of energy sensor 2604*c* can notify the network management system 2601 by way of the base station 2614.

The noise sensor 2604*d* can be used to measure noise on the power line 2610 that may adversely affect transmission of electromagnetic waves on the power line 2610. The noise sensor 2604*d* can sense unexpected electromagnetic interference, noise bursts, or other sources of impairments that may interrupt transmission of modulated electromagnetic waves on a surface of a power line 2610. A noise burst can be caused by, for example, a corona discharge, or other source of noise. The noise sensor 2604*d* can compare the measured noise to a noise profile obtained by the waveguide system 2602 from an internal database of noise profiles or from a remotely located database that stores noise profiles via pattern recognition, an expert system, regression or other statistical modeling, curve fitting, matched filtering or other artificial intelligence, classification or comparison technique. From the comparison, the noise sensor 2604*d* may identify a noise source (e.g., corona discharge or otherwise) based on, for example, the noise profile that provides the closest match to the measured noise. The noise sensor 2604*d* can also detect how noise affects transmissions by measuring transmission metrics such as bit error rate, packet loss rate, jitter, packet retransmission requests, etc. The noise sensor 2604*d* can report to the network management system 2601 by way of the base station 2614 the identity of noise sources, their time of occurrence, and transmission metrics, among other things.

The vibration sensor 2604*e* can include accelerometers and/or gyroscopes to detect 2D or 3D vibrations on the power line 2610. The vibrations can be compared to vibration profiles that can be stored locally in the waveguide system 2602, or obtained by the waveguide system 2602 from a remote database via pattern recognition, an expert system, regression or other statistical modeling, curve fitting, matched filtering or other artificial intelligence, classification or comparison technique. Vibration profiles can be used, for example, to distinguish vibrations caused by fallen trees/branches from vibrations caused by wind and wind gusts (e.g., galloping, Aeolian vibrations, etc.) based on, for example, the vibration profile that provides the closest match to the measured vibrations. The results of this analysis can be reported by the vibration sensor 2604*e* to the network management system 2601 by way of the base station 2614.

The environmental sensor 2604*f* can include a barometer for measuring atmospheric pressure, ambient temperature (which can be provided by the temperature sensor 2604*a*), wind speed, humidity, wind direction, and rainfall, among other things. The environmental sensor 2604*f* can collect raw information and process this information by comparing it to environmental profiles that can be obtained from a memory of the waveguide system 2602 or a remote database to predict weather conditions before they arise via pattern recognition, an expert system, knowledge-based system or other artificial intelligence, classification or other weather modelling and prediction techniques. The environmental sensor 2604*f* can report raw data as well as its analysis to the network management system 2601.

The image sensor 2604*g* can be a digital camera (e.g., a charged coupled device or CCD imager) for capturing images in a vicinity of the waveguide system 2602. The image sensor 2604*g* can include an electromechanical mechanism to control movement of the camera for inspecting the power line 2610 from multiple perspectives (e.g., top surface, bottom surface, left surface, right surface and so on). The collection and retrieval of imaging data generated by the image sensor 2604*g* can be controlled by the network management system 2601, or can be autonomously collected and reported by the image sensor 2604*g* to the network management system 2601.

Other sensors that may be suitable for collecting telemetry information associated with the waveguide system 2602 and/or the power lines 2610 for purposes of detecting, locating and predicting and/or mitigating impairments that can impede electromagnetic wave transmissions on power lines 2610 (or any other form of a transmission medium of electromagnetic waves) may be utilized by the waveguide system 2602.

As described above, impairment detection sensor 2604*b* can perform measurements on the power line 2610 to detect impairments such as signal reflections, which may indicate a presence and location of a downstream impairment that may impede the propagation of electromagnetic waves on the power line 2610. A signal reflection can represent a distortion resulting from, for example, an electromagnetic wave transmitted on the power line 2610 by the waveguide 2606 that reflects in whole or in part back to the waveguide 2606 from an impairment in the power line 2610 located downstream from the waveguide 2606. In addition, image sensor 2604*g* can indicate an approximate azimuthal orientation of an impairment by analyzing image data to recognize a branch on top of a power line, an icicle hanging at the bottom of a power line, a layer of guano, etc.

In an embodiment, a training controller of waveguide system 2602, such as training controller 1900, 2425 or 2435 is coupled to receive data from these sensors. The data from these sensors can be used by training controller to facilitate the detection of impairments and/or to otherwise assist the training controller in training or adjusting the characteristics of the electromagnetic waves to enhance the propagation and/or maximize data throughput. In various embodiments, the training controller of waveguide system 2602 can select one or more carrier frequencies as a function of one or more different temperature measurements, the presence or absence of impairments, vibrations, and environmental conditions, and/or a noise measurement to generate an asymmetrical mode with a desired propagation, to operate within a limited range of the cutoff frequency of a desired asymmetrical mode and/or to adjust the envelope of the electromagnetic waves with an envelope having local minima and maxima at locations that enhance propagation and/or reduce interference. The training controller of waveguide system 2602 can optionally select one of a plurality of modulations, a depth of error correction, or one of a plurality of MIMO modes to enhance the propagation and/or maximize data throughput. For example, the training controller of waveguide system 2602 operates in conjunction with sensors to detect impairments, and triggers retraining of the communications link, adjusting

the formatting, modulation or adjusting the characteristics of the electromagnetic waves in an attempt to compensate for the impairments.

In some embodiments, the training controller of waveguide system **2602** detects an impairment on the outer surface of the transmission medium that is adverse to the transmission of the electromagnetic waves and adjusts the envelope of the electromagnetic waves to enhance propagation or throughput in the presence of this impairment. For example, the training controller of waveguide system **2602** can adjust local minima and/or maxima of the envelope to locations to help compensate for the impairment. In particular, when an impairment occurs at a particular position along the power line **2610**, the training controller can adjust the envelope the electromagnetic waves to place a local minimum of the envelope in a location that corresponds to a position of the impairment on the outer surface of the single wire transmission medium—reducing the adverse effects of the impairment on the electromagnetic waves.

Consider the case where an impairment occurs at a particular azimuthal orientation and displacement along the power line **2610**. The training controller of waveguide system **2610** can adjust the envelope of the electromagnetic waves to place a local minimum of the envelope at the particular azimuthal orientation and displacement that corresponds to this impairment. For example, location data from the sensors can indicate the displacement and/or azimuthal orientation of the impairment. The training controller can include a look-up table or algorithm that generates adjustments to the envelope of the electromagnetic waves to explicitly place a local minimum at or near the location of the impairment while optionally maintaining as closely as possible other minima at interfering couplers of local or remote transmitters and maxima at locations of the couplers of remote receivers.

In another example, the training controller of waveguide system **2602** can react to the detection of an impairment or possible impairment by testing over possible frequencies to generate characteristics of the electromagnetic waves that enhance throughput by producing an envelope with a local minimum at or near the location of the impairment. Feedback data received from one or more remote transmission devices coupled to receive the electromagnetic waves can be used to guide the training process. In particular, the feedback data can include, or be used to generate, a packet error rate, a bit error rate, a signal strength of the received signal, a signal to noise ratio, a data throughput measurement or other quality of the transmission link that can be used by the training controller to evaluate a plurality of electromagnetic wave candidates and to select an electromagnetic wave candidate with characteristics that enhances propagation or throughput.

In addition, to the use of sensors, waveguide system **2602** can also detect impairments that adversely affect the transmission or reception of electromagnetic waves via the analysis of feedback data received from a remote transmission device, such as another waveguide transmission device that is remotely located along the power line **2610** that is coupled to communicate with the waveguide system **2602**. For example, an impairment on the outer surface of the single wire transmission medium can be detected is based on detecting an absence of feedback data such as acknowledgement data or other feedback from the remote transmission device. The absence of periodic test signal transmissions or other expected transmissions from the remote transmission device can also be used to detect an impairment and be used to trigger retraining by the training controller.

FIG. **28** is a block diagram illustrating an example, non-limiting embodiment of a system **2800** for managing a power grid **2803** and a communication system **2805** embedded therein in accordance with various aspects described herein. The communication system **2805** comprises a plurality of waveguide systems **2602** coupled to power lines **2610** of the power grid **2803**. At least a portion of the waveguide systems **2602** used in the communication system **2805** can be in direct communication with a base station **2614** and/or the network management system **2601**. Waveguide systems **2602** not directly connected to a base station **2614** or the network management system **2601** can engage in communication sessions with either a base station **2614** or the network management system **2601** by way of other downstream waveguide systems **2602** connected to a base station **2614** or the network management system **2601**.

The network management system **2601** can be communicatively coupled to equipment of a utility company **2802** and equipment of a communications service provider **2804** for providing each entity, status information associated with the power grid **2803** and the communication system **2805**, respectively. The network management system **2601**, the equipment of the utility company **2802**, and the communications service provider **2804** can access communication devices utilized by utility company personnel **2806** and/or communication devices utilized by communications service provider personnel **2808** for purposes of providing status information and/or for directing such personnel in the management of the power grid **2803** and/or communication system **2805**.

In an example of operation, waveguide system **2602** transmits and receives messages embedded in modulated electromagnetic waves traveling along a surface of a power line **2610**. The messages can be voice messages, streaming video, and/or other data exchanged between communication devices communicatively coupled to the communication system **2805**. The sensors **2604** of the waveguide system **2602** can collect sensing data. The waveguide system **2602** (or the sensors **2604** themselves) can determine from the sensing data an actual or predicted occurrence of an impairment in the communication system **2805** that can affect communications originating from or received by the waveguide system **2602**. The waveguide system **2602** (or the sensors **2604**) can process temperature data, signal reflection data, loss of energy data, noise data, vibration data, environmental data, or any combination thereof to make this determination. The waveguide system **2602** (or the sensors **2604**) may also identify the source of the impairment and/or its location in the communication system **2805**. If an impairment is neither detected nor predicted, the waveguide system **2602** can continue to transmit and receive messages embedded in modulated electromagnetic waves traveling along a surface of the power line **2610**.

If an impairment is detected or predicted to occur, the waveguide system **2602** determines if the impairment adversely affects transmission or reception of messages in the communication system **2805**. In one embodiment, a duration threshold and a frequency of occurrence threshold can be used to determine when an impairment adversely affects communications in the communication system **2805**. For illustration purposes only, assume a duration threshold is set to 500 ms, while a frequency of occurrence threshold is set to 5 impairments occurring in an observation period of 10 sec. Thus, an impairment having a duration greater than 500 ms will trigger the duration threshold. Additionally, any impairment occurring more than 5 times in a 10 sec time interval will trigger the frequency of occurrence threshold.

In one embodiment, an impairment may be considered to adversely affect signal integrity in the communication system

2805 when the duration threshold alone is exceeded. In another embodiment, an impairment may be considered as adversely affecting signal integrity in the communication system **2805** when both the duration threshold and the frequency of occurrence threshold are exceeded. The latter embodiment is thus more conservative than the former embodiment for classifying impairments that adversely affect signal integrity in the communication system **2805**.

If the impairment detected neither exceeds the duration threshold nor the frequency of occurrence threshold, the waveguide system **2602** may continue to process messages. For instance, if the impairment detected has a duration of 1 ms with a single occurrence in a 10 sec time period, then neither threshold will be exceeded. Consequently, such an impairment may be considered as having a nominal effect on signal integrity in the communication system **2805** and thus would not be flagged as an impairment requiring mitigation. Although not flagged, the occurrence of the impairment, its time of occurrence, its frequency of occurrence, spectral data, and/or other useful information, may be reported to the network management system **2601** as telemetry data for monitoring purposes.

If, on the other hand, the impairment exceeds either or both thresholds, the waveguide system **2602** can report the incident to the network management system **2601**. The report can include raw sensing data collected by the sensors **2604**, a description of the impairment if known by the waveguide system **2602**, a time of occurrence of the impairment, a frequency of occurrence of the impairment, parameters readings such as bit error rate, packet loss rate, retransmission requests, jitter, latency and so on. If the impairment is based on a prediction by one or more sensors of the waveguide system **2602**, the report can include a type of impairment expected, and if predictable, an expected time occurrence of the impairment, and an expected frequency of occurrence of the predicted impairment when the prediction is based on historical sensing data collected by the sensors **2604** of the waveguide system **2602**.

FIG. **29** is a diagram illustrating an example, non-limiting embodiment of an electromagnetic distribution in accordance with various aspects described herein. In particular, an electromagnetic distribution **2900** is presented in two dimensions for a transmission device that includes any of the couplers previously described. The electromagnetic wave **2902** propagates along an outer surface of a transmission medium **2904**, such as a single wire transmission medium or other transmission medium previously discussed.

The majority of the energy of the electromagnetic wave **2902** that propagates along the transmission medium **2904** is outside of, but in close proximity to the outer surface of the transmission medium **2904**. The combination of symmetrical and asymmetrical propagation mode(s) of the electromagnetic wave **2904** forms an envelope that varies as a function of azimuthal orientation as well as a function of the longitudinal displacement along the transmission medium **2904**. The envelope of the electromagnetic wave **2902** roughly follows a serpentine pattern, oscillating between minima and maxima and concentration along the top and bottom of the transmission medium **2904**, as the electromagnetic wave **2902** propagates along the direction of propagation **2906**.

Consider an azimuthal orientation $\theta=0$ that corresponds to the bottom of the transmission medium **2904**. The opposite surface, at the top of the transmission medium **2904**, corresponds to $\theta=\pi$, an azimuthal orientation of π radians. In the embodiment shown, for $\theta=0$ the envelope has local maxima at (x_1, x_3, x_5, x_7) and a local minima at (x_2, x_4, x_6). Conversely, for $\theta=\pi$, the envelope has local minima at (x_1, x_3, x_5, x_7) and a local maxima at (x_2, x_4, x_6).

If an impairment, for example a tree branch, occurs at x_7, this can block or otherwise impede the propagation of the electromagnetic wave **2902**, adversely affecting the transport of the communication data conveyed by the electromagnetic wave **2902**. As previously discussed, a training controller associated with the transmission device can detect the impairment and adjust the envelope of the electromagnetic waves **2902** to place a local minimum of the envelope in the location x_7 that corresponds to the position of the impairment on the transmission medium **2904**.

FIG. **30** is a diagram illustrating an example, non-limiting embodiment of an electromagnetic distribution in accordance with various aspects described herein. In particular, an electromagnetic distribution **3000** is presented in two dimensions for a transmission device that includes any of the couplers previously described. The electromagnetic wave **3002** propagates along an outer surface of a transmission medium **2904**, such as a single wire transmission medium or other transmission medium previously discussed in conjunction with the example of FIG. **29**. In this example, the training controller has adjusted the envelope of the electromagnetic wave **3002** to place a local minimum of the envelope in the location x_7 that corresponds to the position of the impairment on the transmission medium **2904**. Because the location x_7 that corresponds to the position of the impairment corresponds to a local minimum of the envelope, the effect of the impairment on the propagation of the electromagnetic wave **3002** is greatly reduced.

Turning now to FIG. **31**, a flow diagram is shown illustrating an example, non-limiting embodiment of a method of transmission **3100**. The method can be used in conjunction with one or more functions and features described in conjunction with FIGS. **1-30**. Step **3102** includes facilitating transmission or reception of electromagnetic waves that propagate along an outer surface of a single wire transmission medium via a transmission device, wherein the electromagnetic waves transport communications data. Step **3104** includes detecting an impairment on the outer surface of the single wire transmission medium that is adverse to the transmission of the electromagnetic waves. Step **3106** includes adjusting an envelope of the electromagnetic waves to place a local minimum of the envelope in a location that corresponds to a position of the impairment on the outer surface of the single wire transmission medium.

In an embodiment, step **3106** includes adjusting at least one carrier frequency of the electromagnetic waves based on feedback data received from at least one remote transmission device coupled to receive the electromagnetic waves. The method can further include facilitating detection of the impairment via one or more sensors. Step **3104** can be based on transmitting electromagnetic wave test signals on the single wire transmission medium, data received from one or more sensors and/or detecting the absence of acknowledgement signals or other feedback from a remote transmission device.

The method can further include coordinating the adjusting of at least one carrier frequency of the electromagnetic waves with the at least one remote transmission device coupled to receive the electromagnetic waves. The single wire transmission medium can be a power line of a power grid for distribution of electric power.

As used herein, "microwave" refers to waves in a frequency range of 300 MHz to 300 GHz. "Millimeter wave" refers to waves in a frequency range of 30 GHz to 300 GHz.

As used herein, terms such as "data storage," "database," and substantially any other information storage component relevant to operation and functionality of a component, refer to "memory components," or entities embodied in a "memory" or components comprising the memory. It will be appreciated that the memory components or computer-readable storage media, described herein can be either volatile memory or nonvolatile memory or can include both volatile and nonvolatile memory.

In addition, a flow diagram may include a "start" and/or "continue" indication. The "start" and "continue" indications reflect that the steps presented can optionally be incorporated in or otherwise used in conjunction with other routines. In this context, "start" indicates the beginning of the first step presented and may be preceded by other activities not specifically shown. Further, the "continue" indication reflects that the steps presented may be performed multiple times and/or may be succeeded by other activities not specifically shown. Further, while a flow diagram indicates a particular ordering of steps, other orderings are likewise possible provided that the principles of causality are maintained.

As may also be used herein, the term(s) "operably coupled to", "coupled to", and/or "coupling" includes direct coupling between items and/or indirect coupling between items via one or more intervening items. Such items and intervening items include, but are not limited to, junctions, communication paths, components, circuit elements, circuits, functional blocks, and/or devices. As an example of indirect coupling, a signal conveyed from a first item to a second item may be modified by one or more intervening items by modifying the form, nature or format of information in a signal, while one or more elements of the information in the signal are nevertheless conveyed in a manner than can be recognized by the second item. In a further example of indirect coupling, an action in a first item can cause a reaction on the second item, as a result of actions and/or reactions in one or more intervening items.

What has been described above includes mere examples of various embodiments. It is, of course, not possible to describe every conceivable combination of components or methodologies for purposes of describing these examples, but one of ordinary skill in the art can recognize that many further combinations and permutations of the present embodiments are possible. Accordingly, the embodiments disclosed and/or claimed herein are intended to embrace all such alterations, modifications and variations that fall within the spirit and scope of the appended claims. Furthermore, to the extent that the term "includes" is used in either the detailed description or the claims, such term is intended to be inclusive in a manner similar to the term "comprising" as "comprising" is interpreted when employed as a transitional word in a claim.

What is claimed is:

1. A waveguide system, comprising:

a coupler that is positioned with respect to a transmission medium to facilitate transmission of electromagnetic waves that propagate along an outer surface of the transmission medium, wherein the electromagnetic waves transport communications data; and

a training controller that detects an impairment on at least a portion of the outer surface of the transmission medium that is adverse to the transmission of the electromagnetic waves and that adjusts the electromagnetic waves to reduce adverse effects of the impairment, wherein the training controller adjusts an envelope of the electromagnetic waves to place a local minimum of the envelope in a location that corresponds to at least one of: a position of the impairment on the at least the portion of the outer surface of the transmission medium or azimuthal orientation of the impairment on the outer surface of the transmission medium.

2. The waveguide system of claim **1**, wherein the training controller adjusts an envelope of the electromagnetic waves by adjusting at least one carrier frequency of the electromagnetic waves based on feedback data received from at least one remote transmission device coupled to receive the electromagnetic waves.

3. The waveguide system of claim **2**, wherein the training controller coordinates the adjusting of the at least one carrier frequency of the electromagnetic waves with the at least one remote transmission device coupled to receive the electromagnetic waves.

4. The waveguide system of claim **1**, further comprising a sensor that facilitates detection of the impairment by the training controller.

5. The waveguide system of claim **1**, wherein the transmission medium comprises a single wire transmission medium.

6. The waveguide system of claim **1**, wherein the transmission medium comprises a power line of a power grid for distribution of electric power.

7. The waveguide system of claim **1**, wherein detecting the impairment on the at least the portion of the outer surface of the transmission medium is based on transmission of electromagnetic wave test signals on the transmission medium.

8. The waveguide system of claim **1**, wherein the location that corresponds to the impairment on the at least the portion of the outer surface of the transmission medium, includes a displacement and an azimuthal orientation.

9. The waveguide system of claim **1**, wherein detecting the impairment on the at least the portion of the outer surface of the transmission medium is based on detecting an absence of acknowledgement data from at least one remote transmission device.

10. A method comprising:

facilitating, via a transmission device, transmission or reception of electromagnetic waves that propagate along an outer surface of a transmission medium, wherein the electromagnetic waves transport communications data;

detecting an impairment on the outer surface of the transmission medium that is adverse to the transmission of the electromagnetic waves; and

adjusting an envelope of the electromagnetic waves to mitigate adverse effects of the impairment, wherein adjusting the envelope of the electromagnetic waves includes adjusting at least one carrier frequency of the electromagnetic waves based on feedback data received from at least one remote transmission device coupled to receive the electromagnetic waves.

11. The method of claim **10**, wherein adjusting the envelope of the electromagnetic waves includes placing a local minimum of the envelope in a location that corresponds to a position of the impairment on the outer surface of the transmission medium.

12. The method of claim **10**, further comprising:

coordinating the adjusting of the at least one carrier frequency of the electromagnetic waves with the at least one remote transmission device coupled to receive the electromagnetic waves.

13. The method of claim **10**, further comprising:

facilitating detection of the impairment via a sensor.

14. The method of claim **10**, wherein the transmission medium comprises a power line of a power grid for distribution of electric power.

15. The method of claim 10, wherein detecting the impairment on the outer surface of the transmission medium is based on transmitting electromagnetic wave test signals on the transmission medium.

16. The method of claim 10, wherein detecting the impairment on the outer surface of the transmission medium is based on detecting an absence of acknowledgement data from at least one remote transmission device.

17. A waveguide system, comprising:

a transmission device including a coupler, wherein the coupler is positioned with respect to a transmission medium to facilitate transmission or reception of electromagnetic waves that propagate along an outer surface of the transmission medium; and

a training controller, coupled to the transmission device, that detects an impairment on the transmission medium adverse to the transmission or reception of the electromagnetic waves and that adjusts the electromagnetic waves to place a local minimum in a location that corresponds to the impairment on the transmission medium.

18. The waveguide system of claim 17, wherein the training controller adjusts an envelope of the electromagnetic waves by adjusting at least one carrier frequency of the electromagnetic waves based on feedback data received from at least one remote transmission device coupled to receive the electromagnetic waves.

19. The waveguide system of claim 17, wherein the training controller detects the impairment on the transmission medium based on feedback data received from at least one remote transmission device coupled to receive the electromagnetic waves.

20. The waveguide system of claim 17, wherein the training controller detects the impairment on the transmission medium based on an absence of feedback data received from at least one remote transmission device coupled to receive the electromagnetic waves.

21. The waveguide system of claim 17, wherein the location that corresponds to the impairment on the transmission medium, includes a displacement and an azimuthal orientation.

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